

Description

This invention relates generally to a method of logging a well using a tracer which is, at least initially, non-radioactive

5 During the development and operation of oil or gas wells, various types of logs are sometimes obtained for providing information about the conditions or geological structures of the downhole environment of the well. Pressure, temperature, resistivity, porosity, fracture locations, fracture types, fracture numbers, fracture thicknesses and fracturing method effectiveness are examples of information sought to be obtained from various logging techniques. These techniques have included mechanical, electrical and radiological methods. It is the radiological methods to which the present invention relates.

10 In performing radiological logging methods, different nuclear or atomic reactions or characteristics are detected. For example, in a known neutron-neutron logging operation, the relative neutron absorptabilities of different materials found in an earthen formation traversed by the well are used to show the distinctions between such materials and their relative locations in the formation. In neutron-gamma logging, gamma radiation is detected to show the distinctions. During such logging operations the detected characteristics are induced by an external source of neutrons that bombards naturally occurring materials. One shortcoming of these techniques is their lack of sensitivity or ability to clearly distinguish among the various radioactivities or absorptabilities of the various types of substances naturally found in the formation, which substances are not known to the personnel conducting the tests without first conducting some other type of test (for example, the taking of a core sample). Such other test would slow down the radiological logging techniques and thereby defeat one of their benefits, which is their ability to be relatively quickly performed.

15 Another radiological method includes injecting into the earthen formation a known radioactive substance, such as a radioactive isotope-coated propping agent, which can be readily traced as to its location within the formation. This method has been implemented with both radioactive isotope-coated particulate proppant and with radioactive liquids or solutions. A significant shortcoming of this method is the risk of exposure or contamination of personnel, equipment and the environment at the surface of the well where such radioactive substances must be handled by personnel under whatever weather conditions exist at the time. This risk of exposure or contamination also exists with respect to the well bore equipment through which the radioactive substance must flow and with respect to the formations into which the radioactive substance may uncontrollably flow. Additionally, if the radioactive proppant flows back up the well, there is the risk of a possibly uncontrollable exposure or contamination at the surface. Another disadvantage of this prior method is that because all of the injected substance is radioactive at the time it is injected, the entire injected quantity continues to radioactively decay so that additional logs cannot be run in the future until the injected material has sufficiently decayed.

20 A more indirect radiological method for determining features of the downhole earthen formation, and one from which no direct downhole log is obtained, is disclosed in U.S. Patent 3, 002, 091 to Armstrong. The Armstrong method pertains to a non-radioactive material which is flowed into one well, through a formation and out of another well, at which point of production from the second well the material is irradiated at the surface to determine how much of the material made it through the formation, thereby giving some indication of the nature of the formation. A shortcoming of this technique is that it produces a radioactive substance at the surface of the second well, which radioactive substance need to be carefully handled and disposed of to prevent exposure and contamination. Thus, this initially non-radioactive method still poses exposure and contamination risks by being subsequently made radioactive at the surface after it has flowed through the formation. Additionally, this technique does not identify specific locations of features of the earthen formation.

25 In the hydrology art, nuclear logging techniques are also used. In the technical report "Nuclear Well Logging in Hydrology" 1971, pages 43 to 50 (published by International Atomic Agency, Vienna), reference is made to the use both of radioactive tracers and of certain non-radioactive tracers.

30 We have now devised a method of well logging which uses a tracer which is, at least initially, non-radioactive. In accordance with the present invention, the tracer is irradiated with neutrons before it is deposited in the earthen formation. Thus, the present invention provides a method of logging a well, comprising moving a tracer into the well so that the tracer is deposited in an earthen formation of the well, the tracer being non-radioactive at least until just prior to entering the well ; irradiating the tracer so that it exhibits at least one tracer characteristic distinguishable from earthen formation characteristics ; and detecting the at least one tracer characteristic after the tracer has been deposited in the earthen formation, characterised in that the step of irradiating the tracer includes passing it through a source of neutrons before it is deposited in the earthen formation.

35 The invention also includes a method of detecting a fracture in an earthen formation of a well, comprising

locating a source of neutrons near the mouth of the well ; moving into the source of neutrons a neutron-responsive non-radioactive isotope tracer, converting the neutron-responsive non-radioactive isotope within the source of neutrons into a radioactive isotope tracer ; moving the radioactive isotope tracer from the source of neutrons into the well for depositing in the fracture ; and detecting the radioactivity emitted from the radioactive isotope tracer deposited in the fracture.

Since the tracer is initially non-radioactive, it can be easily and safely maintained and handled at the surface of the well without concern for radioactive exposure or contamination. When it has been put into the injection system, it is irradiated and made radioactive just prior to entering the well. The method of the present invention is readily controllable as to where the material is to be deposited and as to how much is to be radiologically activated, and the method can be implemented to produce several logs over time using only a single injection of the tracer. The present invention can be implemented with known equipment, such as of the type previously used in neutron-neutron logging and neutron-gamma logging operations. Through use of the present invention, specific information about the location of features in the earthen formation can be directly obtained.

In one embodiment of the present invention, the tracer is irradiated to an extent such that not all of it exhibits the tracer characteristic, and wherein after the tracer has been deposited in the earthen formation, a source of neutrons is lowered into the well and activated to emit neutrons into the earthen formation so that the remainder of the tracer then exhibits at least one tracer characteristic in response to the emitted neutrons. Preferably, in this procedure, the step of detecting the at least one tracer characteristic of the remainder of the tracer comprises lowering into the well neutron detector means for detecting the relative difference between the absorption of neutrons by the earthen formation and the absorption of neutrons by the remainder of the tracer after the tracer has been deposited within the earthen formation.

In order that the invention may be more fully understood, reference is made to the accompanying drawings. Figure 1 describes certain techniques and procedures which do not fall within the scope of the invention but the description thereof is of assistance to an understanding of Figure 2 which describes a method in accordance with the invention.

In the drawings :

Figure 1 is a schematic sectional view of a well ; and Figure 2 is a diagram illustrating irradiation of tracer prior to entry into the well.

Generally, the method of the present invention comprises the steps of moving into a well a tracer, which is non-radioactive at least until just prior to entering the well, so that the tracer will be deposited in an earthen formation of the well ; and then detecting the at least one tracer characteristic after the tracer has been deposited in the earthen formation. As used herein, the phrase "just prior to entering the well" means a location from which further movement of the material is in a substantially closed system which ultimately communicates with the well bore so that there is little risk of the material, should it then be radioactive, exposing or contaminating anything outside the system. As the tracer is so defined, however, it need never become radioactive so that it then remains radiologically safe wherever it is. As used herein, "irradiating" is given a broad definition of by some means exposing to radiation, particularly nuclear or atomic radiation, including but not necessarily limited to gamma radiation or to the emission of alpha or beta particles or of nucleons.

With reference to FIG. 1, a well 2 is shown bored into the earth 4 so that the well traverses or intersects one or more earthen formations which may include one or more different geological strata.

Reference will be made to one earthen formation in which one or more fractures 6 have been formed prior to, or are formed concurrently with, the step of moving the tracer into the well. That is, the procedure as described with reference to FIG. 1 (as well as the embodiment subsequently described with reference to FIG. 2) can be implemented concurrently with a fracturing operation, whereby the tracer is mixed with the fracturing fluid, or it can be implemented after the fracturing operation has occurred.

FIG. 1 also shows a radiation source 8 and a detector 10 concurrently lowered into the well 2 from a logging truck 12. These representations only schematically depict the actual devices as their associated hoisting and recording equipment located at the surface of the well 2 are well known. For example, in one procedure, the source 8 is a downhole accelerator of a type as known to the art for emitting a flux of neutrons to bombard the formation and the deposited tracer. The detector 10 is, by way of example, a Geiger counter or a scintillation detector of known types for detecting gamma radiation or a suitable detector for detecting thermal neutrons, depending upon which reaction or characteristic (i.e., gamma radiation or thermal neutrons) is to be detected, as more particularly described hereinbelow.

FIG. 1 still further shows a tracer 14 which in general is a radiation-responsive substance and which in FIG. 1 specifically includes a particulate proppant made of a suitable material that readily mixes or interfaces, in a non-reactive or otherwise non-deleterious manner, with the carrier fluid, such as the fracturing fluid, carrying the tracer into the well 2. A suitable particulate proppant is the type used in Rayfrac® propping

agents or as disclosed in U.S. Patent 4, 199, 680 to Moon. One specific type of suitable substance includes appropriately sized grains of mold sand. It is to be noted, however, that in general the tracer can be in a suitable form other than particulate (e.g., liquid or foam, or otherwise).

In FIG. 1, the proppant is coated with an infusible resin containing a suitable quantity of a neutron-responsive non-radioactive substance, such as the non-radioactive isotopes of iridium 191, iridium 193, or cadmium 113. Non-radioactive isotopes of boron and indium may also be suitable. The substance which is to be included in the preferred proppant, whether by coating or other suitable association with the carrier element of the proppant, is neutron-responsive so that it readily reacts to neutrons, such as by absorbing thermal neutrons to exhibit a relatively large atomic cross section. By such responsiveness to neutrons, the substance yields the characteristic (e.g., gamma radiation or neutron absorption) which is distinguishable from the characteristics of the materials in the surrounding formation. This substance is also at least initially non-radioactive so that it can be safely handled without fear or risk of radiation exposure or contamination at the surface of the well until it is introduced into the system by which it is to be moved into the well. Although the proppant is initially non-radioactive, the isotope of the proppant is one which either becomes radioactive, whereby the created radioactive isotope decays and emits gamma radiation detectable by a suitable embodiment of the detector 10, or otherwise undergoes a nuclear or atomic reaction, such as by simply absorbing one or more neutrons to an extent greater than the materials of the surrounding formation. Such a reaction occurs in response to the external neutrons emitted from the accelerator 8. If the original substance is to react by forming a radioactive isotope, the radioactive isotope preferably has a known half-life of between approximately a few seconds and approximately 100 days so that prolonged irradiation by the accelerator 8 is not needed for the reaction to occur and so that adequate detection time exists once the conversion has occurred.

For the arrangement shown in FIG. 1, the general step of moving the tagging agent into the well particularly includes depositing a suitable quantity of the neutron-responsive non-radioactive isotope in the fracture in the earthen formation. Such depositing occurs by controlling the carrier substance, such as the fracturing fluid, in creating the fracture or by otherwise conveying the proppant (or other suitable form of the tracer into the fracture. Such depositing can be implemented using known injection equipment of the type used with the aforementioned fracturing fluids. This equipment flows the proppant into the well and builds up relatively large deposits of the proppant in the fractures, as illustrated in FIG. 1 by the proppant 14 located in the fractures 6.

With reference to a tracer which is activated into a radioactive isotope which emits gamma radiation, such as iridium 191 or iridium 193, the general step of irradiating the tracer includes lowering the source 8, such as the aforementioned neutron-source accelerator, into the well 2. In general, this step of lowering is performed after the tracer has been deposited; however, this is not a necessary limitation. The step of irradiating also includes creating with the source 8 atomic reactions in both the earthen formation and the isotope associated with the deposited proppant. These atomic reactions are created by activating the source 8 so that neutrons are emitted into the earthen formation to then activate the tracer, whereupon the activated tracer exhibits the at least one tracer characteristic which is distinguishable from the earthen formation characteristics (i.e., the emission of gamma radiation in this particular description).

In a specific implementation, a suitable downhole accelerator is activated so that the formation and the deposited proppant are exposed to the desired flux of neutrons. The flux of neutrons initially produced by the accelerator comprises a large flux of fast neutrons which ultimately slow down and become thermal neutrons that are absorbed by, or otherwise affect, the non-radioactive isotope associated with the proppant, which isotope thereby is converted into the radioactive isotope. This flux is controlled so that at least a portion of the quantity of the neutron-responsive non-radioactive isotope is converted into the radioactive isotope emitting gamma radiation which is distinguishable from gamma radiation emitted by the earthen formation in response to the bombardment of neutrons from the accelerator.

In this embodiment, the step of detecting the characteristic includes detecting the difference between the atomic reactions of the earthen formation to the neutrons and the atomic reactions of the isotope to the neutrons so that at least one feature of the fracture in which the isotope is deposited is determined. Specifically, the detector 10, in the embodiment of a gamma radiation detector, is lowered into the well for detecting gamma radiation emitted from the tracer after the tracer has been deposited in the earthen formation and after it has been irradiated. As indicated in FIG. 1, the lowering of the detector can be concurrent with lowering of the radiation source 8. Thus, in this configuration, the source 8 is activated for a desired time at one or more locations, and the detector 10 follows to monitor the resultant gamma radiation. By repeating the steps of irradiating and detecting, a multiple-depth or continuous log can be created throughout a selected length of the well.

When the proppant 14 includes cadmium 113, or other suitable material which is particularly good at

absorbing neutrons to an extent greater than the substances likely to be naturally occurring in the earthen formation, the steps are similar to those just described except that the step of creating the atomic reactions includes converting at least a portion of the quantity of the neutron-responsive non-radioactive isotope into a quantity of an isotope having one or more additional nucleons (i.e., neutrons or protons) therein so that neutrons from the source of neutrons are relatively more absorbed in the isotope deposited in the fracture than in the earthen formation. Stated another way, the parent material isotope is transformed into a daughter material isotope with a greater atomic weight. With respect to cadmium 113, at least, this conversion changes the non-radioactive cadmium 113 isotope into another non-radioactive isotope, cadmium 114; therefore, with this specific material even the converted tracer is non-radioactive, which is a significant advantage of this embodiment. Another exception of the neutron-absorbing embodiment over the gamma-radiation embodiment is that the step of detecting the tagging agent characteristic includes lowering into the well a suitable embodiment of the detector 10 by which the relative difference between the absorption of the neutrons by the earthen formation and the absorption of the neutrons by the tagging agent is detected.

The foregoing procedures described with reference to FIG. 1 are particularly suited for producing multiple logs over an indeterminate period of time (which may even extend well beyond the half-life of the radioactive isotope into which the original proppant isotope is converted in the one arrangement) without having to reinject any additional material. For this specific adaptation of making multiple logs, the steps are similar to those already described except that attention is given to how much of the original deposited quantity is converted during each logging operation. Generally, the irradiating step of creating atomic reactions includes converting a first portion of the quantity of the neutron-responsive non-radioactive isotope into a quantity of an isotope which gives within the fracture the at least one characteristic that is distinguishable from the characteristics of the earthen formation. Additionally, the overall method further comprises converting, at a time after an earlier performance of the step of detecting the difference between the atomic reactions created by the step of converting the aforementioned first portion, a second portion of the quantity of the neutron-responsive non-radioactive isotope into a separate quantity of an isotope which gives at least one characteristic distinguishable from characteristics of the earthen formation. Following this step, the difference between the at least one characteristic given the separate quantity of isotope and the characteristics of the earthen formation is detected.

One of two techniques is used to control the irradiating of the tracer so that a sufficient quantity of the original non-radioactive isotope remains after the initial logging to provide a deposit which can be subsequently irradiated and detected. In one of the techniques, the step of converting a first portion of the quantity of the non-radioactive isotope includes exposing the originally deposited quantity of the non-radioactive isotope to the source of neutrons and controlling the length of time of the exposure to define the size of the first portion. In the other technique, the size of the converted first portion is controlled or defined by having the step of converting a first portion of the quantity of the non-radioactive isotope include the step of exposing the quantity of the non-radioactive isotope to the source of neutrons for a predetermined time period and by having the step of depositing the original quantity include the step of flowing into the well, as the quantity of the neutron-responsive non-radioactive isotope to be deposited in the fracture, an amount dependent upon the predetermined time period to which the quantity will be exposed to the source of neutrons.

The aforementioned exposure-time and deposited-quantity controls for defining the portion of the original quantity of non-radioactive isotope converted into another isotope are illustrated by the following example wherein it is assumed that a proppant including ten (10) grams of the iridium 191 isotope, in the form of iridic potassium chloride (K_2IrCl_6), has been deposited in the well 2, wherein the temperature is 100°C , for conversion into the radioactive isotope, iridium 192, which emits detectable gamma radiation. Various activities, A, proportional to the converted positions of the deposited quantity will be determined for various activation times of the source 8 (embodied as a neutron accelerator which emits a neutron flux of $\phi = 1.5 \times 10^8$ neutrons/cm²-sec), thereby indicating the need to control either the exposure time or the deposited quantity.

From equations known to the art,

$A = (2.7 \times 10^{-5})(\phi)(\sigma_a)(N_0)(1 - e^{-\lambda t})$ microcuries, where ϕ is the flux of thermal neutrons to which the parent material (i.e., the original non-radioactive substance) is subjected; σ_a is the neutron capture cross section in centimeters² for thermal neutrons of the parent material [which equals the product of

$$(\sigma_{a \text{ at } 293^\circ\text{K}})(\sqrt{\pi}/2)(\sqrt{293/T}),$$

where T is in degrees Kelvin; N_0 is the amount of parent nuclei; λ is the decay constant in seconds⁻¹ of

the newly formed material (which equals $.693/t_{1/2}$, where $t_{1/2}$ = the radioactive half-life in seconds); and t is the period of time during which the parent material is subjected to the neutron flux from the source 8.

Because for any selected isotope and neutron source as used in the present invention, the values of σ_a , λ and ϕ will be known, the principal variables by which the activity A can be changed are the original quantity of the parent material, N_0 , and the time of irradiation, t . Furthermore, because A is proportional to the portion of the parent material that has been converted into the converted isotope (a quantity N), the ability to make subsequent logs using unreacted portions of the original deposit of the propping agent is affected by controlling either the original quantity, N_0 , or the activation time, t , or both. That is, varying the original quantity, N_0 , or the activation time, t , will produce different amounts of activated material downhole.

Continuing with the example, the weight percent of the iridium 191 isotope in the ten grams of iridic potassium chloride is 39.78%. Thus, there are 3.978 grams of the iridium 191 isotope in the tracer, which translates into $N_0 = 1.247 \times 10^{22}$ nuclei. The known neutron cross section of iridium 191 is 750b at 293°K, thus σ_a at the 100° (373°K) temperature of the well is 5.89×10^{-22} cm².

For the iridium 192 radioisotope produced from the irradiated iridium 191 isotope, the half-life, $t_{1/2}$, is 74.4 days; therefore, $\lambda = 1.078 \times 10^{-7}$ sec⁻¹.

The resultant activities of the iridium 192 isotope created downhole from the neutron source for activation times, t , of one second, one minute, one hour and one day are $A_{sec} = 3.20 \times 10^{-3}$ microcuries, $A_{min} = 1.92 \times 10^{-1}$ microcuries, $A_{hr} = 11.54$ microcuries, and $A_{day} = 275.76$ microcuries. These activity values clearly exemplify that as the activation time, t , increases, so does the activity, thereby indicating the conversion of more of the original deposit. This holds true because the term $(1-e^{-\lambda t})$ of the initial equation increases as t increases. It should be noted, however, that $(1-e^{-\lambda t})$ approaches a value of one as t increases to infinity. At a value of $t = 4t_{1/2}$, the $(1-e^{-\lambda t})$ term is at a value of approximately 0.94.

From the foregoing, it has been concluded that the activation time, t , of the neutron source 8 should be limited to a value of less than 4 times the half-life of the isotope to be created by the neutron flux because for activation times greater than this, there is a rapid decrease in activation per unit time of activation. For values of the activation time which are less than $t_{1/2}$, the activation per unit of time of activation is approximately constant.

The foregoing considerations pertaining to converted quantities and multiple logs are addressed primarily to FIG. 1 because FIG. 2 is directed to the present invention wherein the initially non-radioactive tracer is irradiated at the surface of the well after it has been safely put into the injection system, but prior to it flowing into the well. Thus, with the embodiment of FIG. 2, the safety benefits previously described are obtained, but the subsequent use of the surface-irradiated material is substantially the same as in those methods such as of the type used in the Rayfrac® propping agent. Therefore, since irradiation is at the surface in FIG. 2, this procedure is not necessarily concerned with additional activation for taking subsequent logs; however, because the non-radioactive tracer is still used, the surface irradiation can be controlled so that not all of the tracer is activated whereby there could exist unactivated deposits of the non-radioactive isotope, which deposits could be subsequently activated using one of the procedures represented in FIG. 1.

Another distinction of the FIG. 2 procedure from that shown in FIG. 1 is that FIG. 2 is directed to use with materials, such as the iridium 191 and the iridium 193 isotopes, that, upon irradiation, become radioactive with gamma ray emissions. That is, what is to be detected in FIG. 2 is gamma radiation since no source 8 is being used downhole. However, the scope of the invention does not preclude modification of the basic FIG. 2 embodiment to use both a source 8 and a suitable detector downhole.

Briefly, FIG. 2 depicts a source of tracer 16, particularly shown as a mixture of the tracer (in an appropriate form) with a suitable fracturing fluid, providing a flow of the tracer into a radiation source 18, such as a suitable neutron accelerator 20 housed in a protective shield 22 located near the mouth of the well 2 (or otherwise downstream of other surface equipment whereby surface equipment exposure and contamination are minimized). As the non-radioactive isotope-containing tracer passes inside the source 18, the non-radioactive isotope is converted into a radioisotope. Such activated tracer moves from the source 18 into the well 2 for depositing in the fractures. A suitable detector of the gamma radiation detecting type is lowered into the well for detecting the radioactivity emitted from the activated tracer.

Thus, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned above as well as those inherent therein. While preferred embodiments of the invention have been described for the purpose of this disclosure, numerous changes in the construction and arrangement of parts

and the performance of steps can be made by those skilled in the art.

Claims

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1. A method of logging a well (2), comprising moving a tracer into the well so that the tracer is deposited in an earthen formation of the well, the tracer being non-radioactive at least until just prior to entering the well ; irradiating the tracer so that it exhibits at least one tracer characteristic distinguishable from earthen formation characteristics ; and detecting the at least one tracer characteristic after the tracer has been deposited in the earthen formation, characterised in that the step of irradiating the tracer includes passing it through a source (18) of neutrons before it is deposited in the earthen formation.

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2. A method according to claim 1, wherein the step of detecting the at least one tracer characteristic includes lowering into the well a gamma radiation detector means for detecting gamma radiation emitted from the tracer after it has been deposited in the earthen formation.

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3. A method according to claim 1, wherein the tracer is irradiated so that not all of it exhibits said tracer characteristic.

4. A method according to claim 3, wherein after the tracer has been deposited in the earthen formation, a source of neutrons is lowered into the well and activated to emit neutrons into the earthen formation so that the remainder of the tracer then exhibits at least one tracer characteristic in response to the emitted neutrons.

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5. A method according to claim 4, wherein the step of detecting the at least one tracer characteristic of the remainder of the tracer comprises lowering into the well neutron detector means for detecting the relative difference between the absorption of neutrons by the earthen formation and the absorption of neutrons by the remainder of the tracer after the tracer has been deposited within the earthen formation.

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6. A method according to any of claims 1 to 5, wherein the step of irradiating the tracer includes converting it into a radioactive isotope having a known half-life.

7. A method according to claim 6, wherein the step of converting the tracer includes emitting neutrons at it for a period of time less than approximately four times the known half-life of the radioactive isotope into which the tracer is converted.

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8. A method of detecting a fracture in an earthen formation of a well (2), comprising locating a source (18) of neutrons near the mouth of the well ; moving into the source of neutrons a neutron-responsive non-radioactive isotope tracer ; converting the neutron-responsive non-radioactive isotope within the source of neutrons into a radioactive isotope tracer ; moving the radioactive isotope tracer from the source of neutrons into the well for depositing in the fracture ; and detecting the radioactivity emitted from the radioactive isotope tracer deposited in the fracture.

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9. A method according to claim 8, wherein the step of moving into the source of neutrons a neutron-responsive non-radioactive isotope tracer includes flowing a particulate proppant having an external coating including an isotope tracer selected from the group consisting of iridium 191 and iridium 193.

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Revendications

1. Procédé de diagrapie d'un puits (1), consistant à : introduire un traceur dans le puits de manière que le traceur se dépose dans une formation terrestre du puits, le traceur étant non radioactif au moins jus- que juste avant de pénétrer dans le puits ; irradier le traceur de manière qu'il présente au moins une caractéristique de traceur pouvant être distinguée des caractéristiques de la formation terrestre ; et détecter la au moins une caractéristique du traceur après que le traceur ait été déposé dans la formation terrestre, caractérisé en ce que la phase d'irradiation du traceur consiste à le faire passer à travers une source (18) de neutrons avant qu'il ne soit déposé dans la formation terrestre.

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2. Procédé selon la revendication 1, dans lequel la phase de détection de la au moins une caractéristique de traceur consiste à descendre dans le puits un moyen détecteur de radiations gamma pour détecter la radiation gamma émise par le traceur après qu'il ait été déposé dans la formation terrestre.

3. Procédé selon la revendication 1, dans lequel le traceur est irradié de manière qu'il ne présente que partiellement ladite caractéristique de traceur.

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4. Procédé selon la revendication 3, dans lequel, après que le traceur ait été déposé dans la formation terrestre, on descend une source de neutrons dans le puits et on l'active pour qu'elle émette des neutrons dans la formation terrestre de façon que la partie restante du traceur présente ensuite au moins une caractéristique de traceur en réponse aux neutrons émis.

and the performance of steps can be made by those skilled in the art.

Claims

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1. A method of logging a well (2), comprising moving a tracer into the well so that the tracer is deposited in an earthen formation of the well, the tracer being non-radioactive at least until just prior to entering the well ; irradiating the tracer so that it exhibits at least one tracer characteristic distinguishable from earthen formation characteristics ; and detecting the at least one tracer characteristic after the tracer has been deposited in the earthen formation, characterised in that the step of irradiating the tracer includes passing it through a source (18) of neutrons before it is deposited in the earthen formation.

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2. A method according to claim 1, wherein the step of detecting the at least one tracer characteristic includes lowering into the well a gamma radiation detector means for detecting gamma radiation emitted from the tracer after it has been deposited in the earthen formation.

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3. A method according to claim 1, wherein the tracer is irradiated so that not all of it exhibits said tracer characteristic.

4. A method according to claim 3, wherein after the tracer has been deposited in the earthen formation, a source of neutrons is lowered into the well and activated to emit neutrons into the earthen formation so that the remainder of the tracer then exhibits at least one tracer characteristic in response to the emitted neutrons.

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5. A method according to claim 4, wherein the step of detecting the at least one tracer characteristic of the remainder of the tracer comprises lowering into the well neutron detector means for detecting the relative difference between the absorption of neutrons by the earthen formation and the absorption of neutrons by the remainder of the tracer after the tracer has been deposited within the earthen formation.

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6. A method according to any of claims 1 to 5, wherein the step of irradiating the tracer includes converting it into a radioactive isotope having a known half-life.

7. A method according to claim 6, wherein the step of converting the tracer includes emitting neutrons at it for a period of time less than approximately four times the known half-life of the radioactive isotope into which the tracer is converted.

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8. A method of detecting a fracture in an earthen formation of a well (2), comprising locating a source (18) of neutrons near the mouth of the well ; moving into the source of neutrons a neutron-responsive non-radioactive isotope tracer ; converting the neutron-responsive non-radioactive isotope within the source of neutrons into a radioactive isotope tracer ; moving the radioactive isotope tracer from the source of neutrons into the well for depositing in the fracture ; and detecting the radioactivity emitted from the radioactive isotope tracer deposited in the fracture.

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9. A method according to claim 8, wherein the step of moving into the source of neutrons a neutron-responsive non-radioactive isotope tracer includes flowing a particulate proppant having an external coating including an isotope tracer selected from the group consisting of iridium 191 and iridium 193.

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Revendications

1. Procédé de diagraphe d'un puits (1), consistant à : introduire un traceur dans le puits de manière que le traceur se dépose dans une formation terrestre du puits, le traceur étant non radioactif au moins jus- que juste avant de pénétrer dans le puits ; irradier le traceur de manière qu'il présente au moins une caractéristique de traceur pouvant être distinguée des caractéristiques de la formation terrestre ; et détecter la au moins une caractéristique du traceur après que le traceur ait été déposé dans la formation terrestre, caractérisé en ce que la phase d'irradiation du traceur consiste à le faire passer à travers une source (18) de neutrons avant qu'il ne soit déposé dans la formation terrestre.

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2. Procédé selon la revendication 1, dans lequel la phase de détection de la au moins une caractéristique de traceur consiste à descendre dans le puits un moyen détecteur de radiations gamma pour détecter la radiation gamma émise par le traceur après qu'il ait été déposé dans la formation terrestre.

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3. Procédé selon la revendication 1, dans lequel le traceur est irradié de manière qu'il ne présente que partiellement ladite caractéristique de traceur.

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4. Procédé selon la revendication 3, dans lequel, après que le traceur ait été déposé dans la formation terrestre, on descend une source de neutrons dans le puits et on l'active pour qu'elle émette des neutrons dans la formation terrestre de façon que la partie restante du traceur présente ensuite au moins une caractéristique de traceur en réponse aux neutrons émis.





5. Procédé selon la revendication 4, dans lequel la phase de détection de la au moins une caractéristique de traceur de la partie restante du traceur consiste à descendre dans le puits des moyens détecteurs de neutrons pour détecter la différence relative entre l'absorption de neutrons par la formation terrestre et l'absorption de neutrons par la partie restante du traceur après que le traceur ait été déposé dans la formation terrestre.

6. Procédé selon l'une quelconque des revendications 1 à 5, dans lequel la phase d'irradiation du traceur consiste à le convertir en un isotope radioactif possédant une période connue.

7. Procédé selon la revendication 6, dans lequel la phase de conversion du traceur consiste à émettre des neutrons vers ce traceur pendant une période d'une durée inférieure à environ 4 fois la période connue de l'isotope radioactif en lequel le traceur est converti.

8. Procédé de détection d'une fracture dans une formation terrestre d'un puits (2), consistant à placer une source (18) de neutrons dans le voisinage de la bouche du puits ; introduire dans la source de neutrons un traceur isotope non radioactif sensible aux neutrons ; convertir l'isotope non radioactif sensible aux neutrons contenu dans la source de neutrons en un traceur isotope radioactif ; introduire le traceur isotope radioactif de la source de neutrons dans le puits pour qu'il se dépose dans la fracture ; et détecter la radioactivité émise par le traceur isotope radioactif déposé dans la fracture.

9. Procédé selon la revendication 8, dans lequel la phase consistant à introduire un traceur isotope non radioactif sensible aux neutrons dans la source de neutrons consiste à injecter un agent de soutènement particulaire possédant un revêtement extérieur qui comprend un traceur isotope choisi dans le groupe composé de l'iridium 191 et de l'iridium 193.

Ansprüche

1. Verfahren zur Bohrlochmessung, bei dem ein Tracer in das Bohrloch eingebracht und in einer Erdformation des Bohrloches abgelagert wird, wobei der Tracer mindestens bis unmittelbar vor dem Eintritt in das Bohrloch nichtradioaktiv ist, der Tracer bestrahlt wird und dadurch wenigstens eine Eigenschaft zeigt, die sich von den Eigenschaften der Erdformation unterscheidet, und die wenigstens eine Eigenschaft des Tracers nach Ablagerung des Tracers in der Erdformation gemessen wird, dadurch gekennzeichnet, daß der Tracer während der Bestrahlung durch eine Neutronenquelle (18) geleitet wird, bevor er in der Erdformation abgelagert wird.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß bei der Messung der wenigstens einen Tracereigenschaft Gammastrahlungsdetektormittel in das Bohrloch abgesenkt werden, um die von dem Tracer nach seiner Ablagerung in der Erdformation emittierte Gammastrahlung zu messen.

3. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß der Tracer in der Weise bestrahlt wird, daß nicht der gesamte Tracer die Tracereigenschaft zeigt.

4. Verfahren nach Anspruch 3, dadurch gekennzeichnet, daß nach Ablagerung des Tracers in der Erdformation eine Neutronenquelle in das Bohrloch abgesenkt und betätigt wird, um Neutronen in die Erdformation zu emittieren, so daß der restliche Tracer auf die emittierten Neutronen anspricht und dann die wenigstens eine Tracereigenschaft zeigt.

5. Verfahren nach Anspruch 4, dadurch gekennzeichnet, daß bei der Messung der wenigstens einen Tracereigenschaft des restlichen Tracers Neutronendetektormittel in das Bohrloch abgesenkt werden, um den relativen Unterschied zwischen der Neutronenabsorption durch die Erdformation und der Neutronenabsorption durch den restlichen Tracer nach Ablagerung des Tracers in der Erdformation zu messen.

6. Verfahren nach einem der Ansprüche 1 bis 5, dadurch gekennzeichnet, daß der Tracer bei der Bestrahlung in ein radioaktives Isotop einer bekannten Halbwertszeit umgewandelt wird.

7. Verfahren nach Anspruch 6, dadurch gekennzeichnet, daß bei der Umwandlung des Tracers auf diesen Neutronen während einer Zeitdauer emittiert werden, die geringer als ungefähr die vierfache bekannte Halbwertszeit des radioaktiven Isotops ist, in das der Tracer umgewandelt wird.

8. Verfahren zum Auffinden eines Spalts in einer Erdformation eines Bohrloches (2), dadurch gekennzeichnet, daß eine Neutronenquelle (18) nahe dem Kopf des Bohrloches angeordnet wird, ein auf Neutronen ansprechendes, nicht radioaktives Tracerisotop in die Neutronenquelle eingebracht wird, das auf Neutronen ansprechende, nicht radioaktive Isotop in der Neutronenquelle in ein radioaktives Tracerisotop umgewandelt wird, das radioaktive Tracerisotop zur Ablagerung in dem Spalt aus der Neutronenquelle in das Bohrloch eingebracht wird, und die von dem in dem Spalt abgelagerten radioaktiven Tracerisotop abgestrahlte Radioaktivität gemessen wird.

9. Verfahren nach Anspruch 8, dadurch gekennzeichnet, daß beim Einbringen eines auf Neutronen ansprechenden, nicht radioaktiven Tracerisotops in die Neutronenquelle durch diese ein körniges Stütz-

mittel geleitet wird, das eine äußere Beschichtung mit einem Tracerisotop aufweist, das aus der Gruppe Iridium 191 und Iridium 193 ausgewählt ist.

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