



(51) International Patent Classification:
G01N 23/222 (2006.01)

(21) International Application Number:
PCT/GB2010/050813

(22) International Filing Date:
18 May 2010 (18.05.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0908534.1 19 May 2009 (19.05.2009) GB

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

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

Published:

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

(54) Title: SAND MONITOR

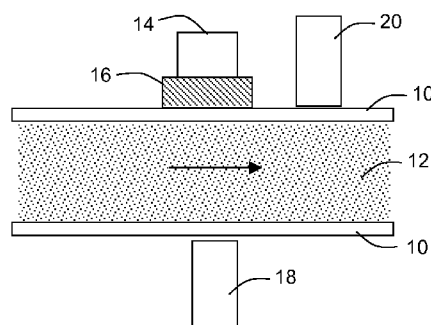


Figure 1

(57) Abstract: The invention comprises a method for measuring the amount of sand or scale in a vessel. The method comprises providing a source of neutrons, causing at least some neutrons produced by said source to interact with the contents of the vessel, and detecting gamma radiation emitted from the vessel over a range of energies including the prompt or delayed gamma peak emission energy of at least one target element known to be present in the sand. An apparatus for use in the method of the invention is also disclosed. The method and apparatus are particularly useful in the oil and gas recovery industry for detecting sand or the formation of scales within a pipeline.

Sand Monitor

The present invention concerns a method for determining the presence of a particular material, especially sand, in a vessel and an apparatus for use in such a method.

The flow of sand from oil and gas-bearing geological formations into production wells is a major problem in the oil and gas production industry. Sand can build up in pipelines and production vessels and the flow of sand with the produced reservoir fluids can damage the valves and vessels it contacts. There are many methods used to control the production of sand, including mechanical methods such as screens and gravel packs which can be used as a physical barrier to prevent the sand from flowing into the well. These methods are expensive to deploy and so the detection and measurement of the amount of sand flowing from a well is important in order to allow deployment of sand control methods in situations when and where it is required. There is therefore a need for an accurate and reliable method of monitoring the amount of sand flowing in a fluid flow. We have found that neutron activated analysis (NAA) may provide a useful method for detecting and measuring sand.

According to the invention we provide a method for measuring the amount of sand in a vessel containing one or more fluid phases comprising the steps of:

- a. providing a source of neutrons;
- b. causing at least some neutrons produced by said source to interact with at least a part of the contents of the vessel;
- c. detecting gamma radiation emitted from the vessel, over a range of energies including at least one characteristic prompt or delayed gamma emission energy peak of at least one target element known to be present in the sand; and
- d. calculating, from the number of photons detected at said at least one prompt or delayed gamma emission energy peak, the amount of said target element present in said part of the contents of vessel.

According to a second aspect of the invention, we provide an apparatus for measuring the amount of sand or scale contained within a vessel containing one or more fluid phases, using the method of the invention, the apparatus comprising:

- a. a source of neutrons;
- b. a detector suitable for detecting high energy gamma emitted from at least one element known to be present in the sand or scale and generating a signal in response thereto; and
- c. means for calculating, from the signal generated by the detector, the amount of said sand or scale within the vessel.

In a preferred embodiment, the fluid comprises an aqueous and/or hydrocarbon fluid flowing within a pipeline. More preferably the fluid comprises at least a portion of the fluid produced from an oil and/or gas production well.

Prompt gamma neutron activated analysis (PGNAA) is a method of detecting the presence of one or more chemical elements by the characteristic emission of prompt gamma radiation when thermal neutrons are captured by nuclei of the element. Near instantaneous gamma photon emissions can also occur through higher energy neutrons colliding inelastically with the target element. The inelastic collision may cause excitation of the nucleus resulting in the release of energy in the form of gamma photons of a characteristic energy resulting in the stabilisation of the nucleus. The gamma photons may be detected and their energy levels measured. The number of photons, i.e. the intensity of the gamma radiation, is indicative of the abundance of the element in the material (or of the target material itself). The target material may be any which contains an element (the "target element") susceptible to produce prompt gamma emission when its nucleus interacts with a neutron and which is identifiable from the energy of such prompt gamma radiation. Prompt-gamma photons emitted from more than one target element may be measured. The ratio of elements may be indicated by the ratio of the intensity of the characteristic peaks of the elements and such ratios may be used to assist in identifying the target material. Where a single element is to be identified, it too may exhibit a characteristic relationship between the intensities of prompt-gamma peaks of different energies, which may be used to identify the element of interest from the energy spectrum.

In addition to utilising the gamma photons produced by thermal neutron interactions it is possible to make elemental analyses from the gamma photons resulting from fast neutron interactions with the target elements. Fast neutrons may undergo inelastic scattering with the target elements, which result in instantaneous emission of characteristic gamma photons. Fast neutrons can also cause the emission of protons from the target nuclei. These neutron / proton (n,p) interactions generate unstable nuclei that for some elements emit gamma photons for a period after activation. This technique is known as delayed neutron activation analysis (DNAA). The n,p reaction for silicon-28 produces aluminium-28. Aluminium-28 has a half-life of approximately two minutes when activated in this manner, which makes down-stream detection possible. The ability to detect the activated sand downstream is beneficial as the gamma photon detection system is located away from the source and thus does not detect gamma photons from neutron interactions with other elements positioned close to the source. The high level of counts due to prompt gammas from hydrogen and other elements in the process media or pipe walls may cause problems for detection systems located close to the neutron source.

The gamma radiation detected in the method and by the apparatus of the invention may be prompt gamma emission, delayed gamma emission or both prompt and delayed gamma emission. As noted above, the prompt gamma emission may be caused by capture of thermal

neutrons by a nucleus of the target element or by inelastic scattering of fast neutrons as they interact with the target element nuclei. The gamma radiation caused by different types of neutron-nucleus interaction have different characteristic energies for each type of element.

5 In a preferred embodiment the target material is sand and the target element for which gamma emission is sought is preferably silicon, although other emission energies characteristic of other elements, such as aluminium, may be monitored in addition to or instead of the silicon energies. Preferably the amount of silicon present in the part of the contents of vessel measured is used to calculate the amount of sand in that part of the vessel. Using measurements made at different times, this calculation may be used or extended to calculate time-dependent properties such as
10 monitoring whether the amount of sand in a part of a vessel changes over a period of time, or monitoring how sand flows along a pipeline or through process apparatus, using the calculated amount of sand at different locations in a vessel, pipeline or process apparatus as appropriate.

The method and apparatus may have other applications, for example to detect elements associated with the formation of scale within a tank or pipeline. In such a case, characteristic
15 prompt and/or delayed gamma emission of appropriate elements known to be present in the scales to be measured, are measured by the detector(s) and used to calculate the amount of the particular scale of interest. Scales vary in composition and so the elements selected for monitoring also vary according to the application. Suitable elements found in oil-field scales include Ba, Fe, Mg, Ca and Sr. Measurement of scale formation may be useful in a decision
20 whether to deploy scale removal operations or to adjust certain process measurements to account for the presence of scale.

When the method is used for monitoring sand or scale produced in an oil and/or gas well, the fluid usually comprises at least one continuous phase of oil, water, gas and discontinuous phases such as emulsions and foam. Frequently the fluid comprises more than one of these
25 materials. A hydrogen-rich fluid, such as a hydrocarbon fluid or water, provides a medium in which fast neutrons, which are capable of passing through a vessel wall, are slowed or moderated to become "thermal neutrons" which may be captured through inelastic collision with the nuclei of materials within the vessel. This makes the use of PGNAO using an isotope source of neutrons especially suitable for the detection of sand in a hydrocarbon and/or water flow.

30 The vessel may be a container such as a tank, drum, pressurised storage container, separator or other process vessel; or it may be a pipeline through which the fluid may flow. The vessel wall may be relatively thick when used to contain or transport fluids under pressure. The method is especially useful for in-line, real-time monitoring, e.g. as fluid flows through a pipeline, because the prompt-gamma emission is immediate upon excitation of a target nucleus by inelastic
35 collision with a thermal neutron and may produce little residual emission when irradiation with neutrons has ceased.

The neutron source is selected from suitable available neutron sources such as neutron generators and radioisotope sources. The selection of an appropriate neutron source should be made according to the situation and application for which the method is applied. Whilst neutron generators may be appropriate to be used in some applications of the method, they tend to be relatively expensive and bulky so may be less practical to use in a compact instrument. The preferred type of neutron source is an isotope source such as californium (^{252}Cf) or americium/beryllium ($^{241}\text{Am/Be}$) which tends to be cheaper and has a longer half-life. These isotope sources emit fast neutrons and, if PGNA is to be employed, these must be slowed to produce thermal neutrons using a moderator which is usually a hydrogen-rich material.

Although a hydrocarbon and water containing fluid within the vessel itself is capable of moderating the fast neutrons, variations in the amount and composition of such fluid may produce variations in the number of thermal neutrons available to interact with the target material. Such variation is likely to affect the accuracy of the measurement due to fluctuations in the intensity of the prompt gamma emission peak. When prompt gamma emissions from the capture of thermal neutrons is used, it is therefore preferred to provide a moderator material between the source and the vessel wall in order to moderate the neutrons before they enter the vessel. Suitable materials are known and include hydrogen-rich materials, especially hydrogen-rich polymers such as polyethylene. Moderation of the neutrons before they enter the vessel also has the advantage that the probability of producing long-term activation of the vessel walls is reduced. If moderation of the neutrons prior to vessel entry is not possible then in one embodiment of the method, the intensity of the hydrogen peak is monitored in order to estimate the degree of thermalisation occurring due to hydrogenous material in the fluid contained in the vessel. This information may then be used to compensate the measured signal intensity for the measured level of thermalisation.

When activation of the target element by both thermal neutrons and fast neutrons is required then the moderator, if provided, may be shaped so that only a portion of the neutrons generated or emitted by the source pass through the moderator before entering the vessel. the moderator may be shaped to include holes through which fast neutrons may pass or the moderator may be shaped and/ or located such that only neutrons emitted from a portion of the source are moderated. Alternatively, more than one source may be provided and in such a case, none, some or all of the sources may be moderated.

If DNAA is to be employed it is beneficial for high-energy neutron sources to be used. Deuterium- tritium neutron generators emit neutrons of 14.4MeV, which are of particular use in producing the silicon n,p reaction

The neutron source should be appropriately shielded and collimated to emit neutrons towards and into the vessel whilst protecting the surrounding environment, personnel and equipment from neutron bombardment. The neutron source may be located outside the vessel adjacent or

near-adjacent (allowing for the presence of a moderator) the vessel wall. In some cases it may be desirable to locate the neutron source within a dip-tube of neutron-permeable material and install the dip-tube at a desired location within a vessel. Such an arrangement may be beneficial when the vessel is very large or when the contents are likely to vary within the vessel. More than one neutron source may be provided for use in the method. The use of multiple neutron sources may be advantageous, as the volume of fluid contents irradiated may thereby be increased, thus increasing sensitivity. The shielding and collimation of the neutron source(s) should be provided as appropriate to the location of the source. The handling of radioisotopes and neutron generators must always be carried out with care by suitably trained personnel with due regard to the necessary licences and procedures.

The gamma radiation emitted from the vessel is detected using an energy-sensitive gamma detector. It is desirable to employ detectors with large sensing elements so that high-energy gamma photons are detected and also to increase the sensitivity of the instrument. The sensitivity of the instrument may also be increased by using more than one detector. Suitable types of detector include scintillation detectors, including, for example, sodium iodide or lanthanum bromide detectors, and semiconductor detectors, for example a germanium detector. The detector(s) may be located outside the vessel in a position selected to detect the emitted gamma photons, close to the vessel. Alternatively the detector may be located within the vessel, optionally within a dip-tube of radiation-permeable material. Location of the detector within a dip-tube provides a protected environment for the detector, whilst allowing more flexibility in selecting its preferred location. Power sources and other equipment for operating the detector(s), such as a photomultiplier, control means, communication means (cables, wireless transmission/reception means) etc are provided by known methods for radiation detectors.

It is preferred that the detector is shielded from detecting directly the neutrons generated by the source and from other sources of gamma radiation. The detector may be positioned on or near a portion of the vessel which is opposite the position of the neutron source or in another position to detect back-scattered photons. More than one detector may be provided. The use of several detectors positioned at locations around the vessel, for example positioned around a particular portion of the vessel of interest, ensures detection of more gamma photons than may be possible by detecting at a single location and this is beneficial to increase the sensitivity of the method and apparatus. A plurality of detectors may be provided in a housing or sleeve which is adapted to be positioned around at least a part of a vessel such that each detector is positioned in a predetermined position relative to the wall of the vessel. One or more of the detectors may be shaped to conform to the surface of the vessel. For example, a plastic scintillation detector may be moulded to form a shape suitable for detecting prompt gamma radiation around at least a portion of the circumference of a vessel, in particular a pipe. When the vessel is a pipeline and the fluid is flowing in the pipe, one or more detectors may be located remote from, e.g. downstream, of the neutron source.

Where the target material is likely to be distributed unevenly within the vessel, for example, where sand may have settled at the bottom of a pipeline or container, the position of the neutron source and detector may need to be selected to provide the required information, e.g. the amount of material in the settled mass or within a flowing fluid. The detection of stationary masses within a pipe containing a flowing fluid may be achieved using one or more conventional flow meters such as an ultrasonic flow meter. When the vessel contains such a dense mass that attenuation of the gamma may be a problem, the instrument should be positioned to minimise attenuation of the neutrons or emitted gamma radiation.

The detector detects an energy spectrum. The gamma radiation emitted over a range of energies including the characteristic gamma peak emission energy due to neutron activation of at least one element known to be present in the target material should be monitored. The output from the detector may be filtered to contain only portion(s) of the energy spectrum known to contain the gamma peak(s) characteristic of the target material. In the case of a sand monitor according to the invention, it is usually the silicon or aluminium peak energies which are of interest. High cross-section silicon prompt gamma peaks from thermal neutron capture, such as 3538 keV, 5 MeV and other energies, are useful characteristic peaks for detecting sand. These peaks have high cross-section at about 0.1 barns. However, the actual peak selected for silicon detection may depend upon the energies of radiation emitted by the presence of other elements that are also activated by the neutrons. For example the thermal capture of neutrons in iron (in the vessel wall) produces many characteristic energies, many of which are around 3.5 MeV and 5 MeV and may make the silicon peaks with the largest cross-sections difficult to resolve. In this case a higher energy silicon peak, such as the one at 8.45 MeV, may be preferred, even though it has a much lower cross-section (0.004 barns). There are about 50 prompt silicon peaks, ranging from about 0.5 to 8.5 MeV and with cross-sections varying from 3×10^{-4} to 0.1 barns. The choice of which prompt silicon characteristic energies to measure and use in the calculation of the amount of silicon present may also be dependent on the resolution capabilities of the detector used.

When delayed gamma emission is to be detected, it is preferred to measure the peak occurring at an energy of about 1.78 MeV. This characteristic energy is emitted from aluminium-28 formed when silicon-28 is activated by the capture of a fast neutron. Prompt gamma emission from inelastic neutron scattering (INS) from silicon also has a useful characteristic energy peak at 1.78 MeV.

There are many different prompt emissions from aluminium thermal neutron capture, with energies ranging from a few KeV to nearly 8 MeV. Also, thermal neutron capture by aluminium-27 can produce aluminium-28 which is the same isotope (producing the same 1.78 MeV photons) producing delayed gamma emission by the capture of a fast neutron by a silicon atom. Knowledge of aluminium:silicon ratios in the sand to be detected may be required in order to

distinguish the photons emitted following interaction of neutrons with Si from those emitted following interaction of neutrons with Al. Calculation of Si content from other detected emissions, especially the prompt gamma emissions, may facilitate identification of Al prompt gamma emissions.

- 5 A sand monitor according to the invention preferably measures counts occurring within one or more energy windows containing the selected silicon peak or peaks. Preferably the gamma radiation emitted from the vessel is detected over a range of energies including at least one characteristic prompt or delayed gamma emission energy peak at about 3.5 MeV, about 5 MeV, about 8.45 MeV and/or about 1.78 MeV. By "about" we mean the energy peak occurring at the
10 stated characteristic energy as measured including a typically acceptable error in the detector. Thus, the measured energy level peak at about 3.5 MeV may vary slightly from 3.5 MeV but nevertheless be identifiable as a characteristic prompt gamma emission from silicon.

- The detector(s) may be calibrated using isotopes of known energy. Once installed the calibration may be confirmed through identification of the hydrogen prompt gamma peak. The
15 hydrogen prompt gamma peak at 2.23 MeV is readily detectable due to the high cross-section of hydrogen, the abundance of hydrogen in the process media and because only a single peak is produced. The position of the hydrogen peak may be tracked during instrument operation to monitor any drift in energy measurements due to factors such as changes in environmental conditions. If any drift in energy measurements is identified, a compensation function may be
20 applied to compensate for the effect, e.g. of temperature, on the gamma detection system. The intensity of the hydrogen peak may be monitored and used as means of producing crude liquid cut measurements in an oilfield application.

- Some of the water / oil contribution to the gamma energies measured may be eliminated through calibration or prior knowledge of the carbon and oxygen prompt energies. A measure of process
25 media bulk density (using known gamma transmission methods) and hence liquid cut may be of use when compensating for carbon and oxygen contribution. However, carbon and oxygen have minimal prompt contribution and compensation may not be required.

- The sand monitor instrument is preferably also calibrated to establish the correlation between silicon gamma intensity, i.e. the number of gamma photons detected at one or more
30 characteristic energy levels, and sand content of the vessel.

- It is possible that the neutrons impinging on the vessel wall may activate the wall material to produce prompt, or even delayed, gamma emissions. The gamma radiation emitted from the vessel wall should not be allowed to interfere with the prompt gamma emissions measured in order to determine the amount of the target material. One method of achieving this is to
35 measure the prompt gamma emitted by the wall material, for example by performing calibration measurements on a sample of the vessel wall (such as an equivalent pipe) and then subtracting

the energy spectrum produced by the vessel wall from the energy spectra produced during the measurement of the target material, for example by using appropriate known spectrum subtraction algorithms in the data processing unit. When only a portion of the energy spectrum is processed, i.e. a narrow window within which the characteristic energy peak is expected to occur, then the wall spectrum may not interfere with the measurement. Alternatively, when using DNAA, the location of a gamma radiation detector at a position remote from the part of the vessel in the path of the neutrons emitted from the source may alleviate this problem. This is particularly suitable for the detection of sand or other elements flowing in a fluid within the vessel. In this way the gamma radiation emitted from the target material can be detected by a detector located downstream (in the direction of fluid flow) of the neutron source so that emission from the vessel wall is not detected. This is a particular benefit of measuring delayed gamma emission from the fluid, in that the gamma radiation may be emitted for sufficient duration for the target material to have flowed away from the location of the neutron source and be detected downstream of the neutron source.

Elements may occur within the vessel material, the fluid, the target material or another material which is present in the vessel that have peaks close to the major characteristic peaks of the selected element of the target material. Test spectra should be examined to identify evidence of the presence of these interfering elements. This evidence may take the form of the prompt or delayed gamma peaks characteristic of the other element identified at energies at parts of the energy spectrum remote from the target element peaks of interest. If interfering elements are found that are known to have peaks close to the energy peaks of interest then compensation may then be applied to the measured peaks. The use of high resolution energy detectors may reduce uncertainty due to neighbouring peaks.

Another cause of uncertainty in measuring the target element characteristic peaks of interest is the detection of photons which were emitted at a higher energy but which then interacted with material and have a reduced energy that coincides with that of the target element peaks of interest. This problem may be reduced by identifying the presence of higher energy peaks, assessing the probability of interaction with process media and vessel / instrument materials and then predicting the level of lower energy photons produced. This prediction may then be used to apply compensation to the target element peak energies. The use of peaks at higher energies to identify and characterise the target element also reduces the potential for this inaccuracy due to this effect.

The sensitivity of the method may be further improved by increasing the counting period of the detectors, i.e. the period of time over which the number of photons of each energy is counted.

In order to reduce the effect of measuring photons scattered by the material of the detector, i.e. which have only been partially absorbed by the detector and which scatter, at least partially, to

cause a further detection event, a Compton shield detector may be provided adjacent the primary detector to detect scattered photons. The number of photons detected by the primary detector may therefore be adjusted to remove scattered photons detected by the Compton shield detector and thereby improve the accuracy of the count of detected photons.

- 5 The calculation of the amount of sand present from the signal generated by the detector(s) is preferably carried out in a data processing unit. The data processing unit may be located near the vessel or may be located remotely, depending on the ambient conditions and operational requirements of the particular application. The control of the detectors, the signal processing, e.g. data smoothing, and calculations such as spectrum subtraction, peak resolution, peak ratio
10 calculation etc is carried out using known methods and algorithms. The data may be output in the form of an energy spectrum so that the elemental composition may be analysed. Alternatively, the data handling program may be programmed to calculate the amount of sand in the vessel from the energy levels which can be identified and attributed to silicon and then to output the answer as a number or show it on a visual display. As a further alternative, the
15 apparatus may be adapted to provide an alarm when the amount of sand changes by a predetermined amount or when it reaches a certain level.

One embodiment of the method and apparatus will be further described as an example of the invention, with reference to the drawings, which are:-

- Figure 1, a schematic longitudinal section through a pipeline and apparatus according to the invention; and
20

Figure 2, a plot of intensity (arbitrary units) vs energy level (keV) for detected prompt gamma emission from a vessel containing water and sand.

- Figure 1 shows, schematically, a section of a pipeline 10 through which a multiphase fluid 12, comprising water, oil and some sand particles, flows in the direction of the arrow. A neutron
25 generating isotope source comprising $^{241}\text{Am}/\text{Be}$ is contained within shielding 14 which is shaped to provide emission of fast neutrons in the direction of the pipeline. In this example, a block of a resilient hydrogen-rich polymer 16 is positioned between the neutron source and the pipeline and serves to moderate the fast neutrons generated by the isotopic source. Gamma detectors
18 and 20 are located to detect gamma energy and generate an energy spectrum. A controller /
30 data processor (not shown in Fig 1) is connected to the detectors to control the signal and data processing function. The downstream detector 20 may be configured to detect a delayed gamma emission energy.

- In use, neutrons generated by the source are emitted towards the pipeline and are moderated to thermal speeds as they pass through the moderating material 16. The neutrons pass through
35 the wall of the pipeline 10 and may interact with matter through inelastic collision with nuclei. Each elemental nucleus capturing a thermal neutron may emit a prompt-gamma photon of an

energy which is characteristic of the identity of the element. The detection of a gamma photon characteristic of silicon is indicative of the presence of sand within the pipeline. The detectors count the number of photons detected and the energy level of each photon during a predetermined time period, (the counting period). The amount of sand detected within a
5 counting period may be estimated from the number of photons counted by the detector having an energy level characteristic of the silicon nucleus, i.e. the intensity or size of the energy peak at that characteristic energy level.

An experiment was carried out by placing a quantity of sand in a metal tank, measuring 50 cm x 50 cm x 50 cm and having a wall thickness of approximately 2mm, filled with tap water. A
10 shielded 18 MBq californium-252 neutron source was placed in a dip-tube inserted into the tank, such that neutrons were emitted into the tank. A 3 inch (75 mm) sodium iodide gamma detector was fixed to the wall of the tank, near the base of the tank in order to be in line with the sand. The counts detected by the detector were measured over a counting period of 60 seconds duration. Figure 2 shows a plot of the counts to show the energy spectrum detected by the
15 detector over the energy level range of 0 – 8000 keV. The energy peak at 3546 keV is attributed to the silicon prompt gamma emission of 3538 keV. Other peaks are believed to indicate emission from other elements as shown in Figure 2.

Claims

1. A method for measuring the amount of sand in a vessel containing one or more fluid phases comprising the steps of:
 - providing a source of neutrons;
 - causing at least some neutrons produced by said source to interact with at least a part of the contents of the vessel;
 - detecting gamma radiation emitted from the vessel, over a range of energies including at least one characteristic prompt or delayed gamma emission energy peak of at least one target element known to be present in the sand; and
 - calculating, from the number of photons detected at said at least one prompt or delayed gamma emission energy peak, the amount of said target element present in said part of the contents of vessel.
2. A method according to claim 1, wherein a neutron moderator is provided between the neutron source and the vessel.
3. A method according to claim 1 or claim 2, wherein the neutron source is located within a dip-tube of neutron-permeable material installed within said vessel.
4. A method according to claim 3, wherein the emitted gamma radiation is detected by more than one gamma detector.
5. A method according to claim 4, wherein at least one of said fluid phases is flowing and at least one gamma radiation detector is located down-stream, with respect to the fluid flow, of the neutron source.
6. A method according to any one of claims 1 – 5, wherein the target element is selected from silicon and aluminium.
7. A method according to claim 6, wherein the target element is silicon.
8. A method according to claim 6 or 7, wherein said at least one characteristic prompt or delayed gamma emission energy peak has an energy of about 3.5 MeV, about 5 MeV, about 8.45 MeV, or about 1.78 MeV.
9. A method according to any one of claims 1 – 8, wherein the fluid comprises one, or more than one, of a fluid selected from water, petroleum and natural gas, mixtures of water and/or petroleum and/or natural gas.
10. A sand monitor, suitable for providing an estimate of the amount of sand contained within a vessel containing water and/or petroleum, comprising:

- a. a source of neutrons, positioned to emit neutrons into the vessel;
 - b. optionally, a neutron moderating material positioned between said source of neutrons and said vessel;
 - c. at least one detector suitable for and positioned for detecting high energy gamma emitted from said vessel and generating a signal in response thereto; and
 - d. means for calculating, from the signal generated by the detector, the amount of silicon contained within a part of the vessel.
11. A sand monitor according to claim 10, wherein said vessel comprises a pipeline through which said water and/or petroleum may flow.
12. A sand monitor according to claim 10 or claim 11, wherein said vessel comprises a separator for separating by gravity a mixture of fluid phases
13. A sand monitor according to any one of claims 10 – 12, wherein a detector is located downstream, with respect to the fluid flow, of the neutron source.

Figure 1

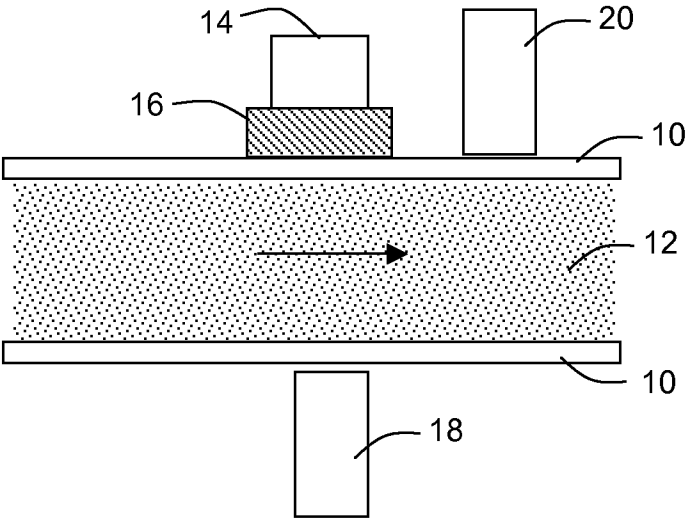
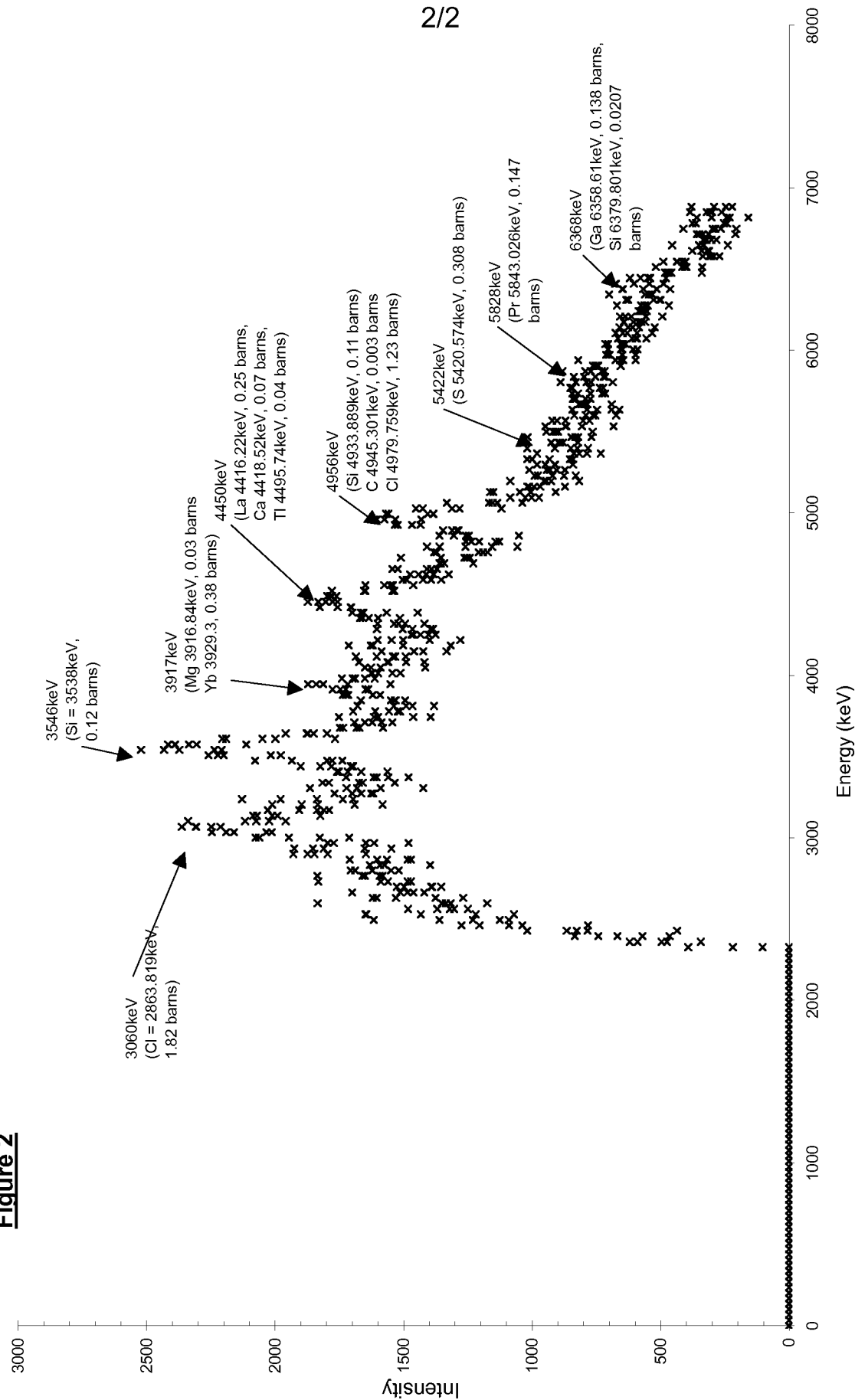


Figure 2



INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2010/050813

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N23/222
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)
G01N

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 practical, search terms used)

EPO-Internal, EMBASE, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>DUFFEY D ET AL: "Analysis of geothermal power plant water using gamma rays from capture of californium 252 neutrons" NUCLEAR TECHNOLOGY, AMERICAN NUCLEAR SOCIETY, CHICAGO, IL, US, vol. 27, no. 3, 1 November 1975 (1975-11-01), pages 488-499, XP009136816 ISSN: 0029-5450</p> <p>* abstract</p> <p>page 489, right-hand column, last paragraph</p> <p>page 491, right-hand column</p> <p>page 493, left-hand column</p> <p>page 494, last paragraph</p> <p>table III</p> <p>figures 14, 15</p> <p style="text-align: center;">----- -/--</p>	1-3,6-11

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

☐ See patent family annex.

* Special categories of cited documents :

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

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Date of the actual completion of the international search

19 August 2010

Date of mailing of the international search report

06/09/2010

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PCT/GB2010/050813

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>WOODBURY FRANKLIN B W: "APPLICATION OF THERMAL NEUTRON CAPTURE-GAMMA RAY ANALYSIS TO OXIDIZED TACONITE BENEFICIATION PROCESS SLURRIES"</p> <p>REPORT OF INVESTIGATIONS, UNITED STATES BUREAU OF MINES, US, no. 8460, 1 January 1980 (1980-01-01), pages 1-71, XP009136764</p> <p>ISSN: 0096-1922</p> <p>figures 1, 3, 8; table I</p>	1,3,6-11
X	<p>DIBBS H P ET AL: "DETERMINATION OF THE COMPOSITION OF SLURRIES BY THE MEASUREMENT OF THERMAL-NEUTRON-CAPTURE GAMMA RADIATION"</p> <p>REPRINT SERIES. MINES BRANCH. DEPARTMENT OF MINES AND TECHNICAL SURVEYS,, 1 January 1972 (1972-01-01), pages 1-24, XP009136779</p> <p>* abstract</p> <p>page 3, last paragraph</p> <p>page 5</p> <p>page 7</p> <p>figure 1</p>	1-3,6-11