

Jan. 22, 1952

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2,583,288

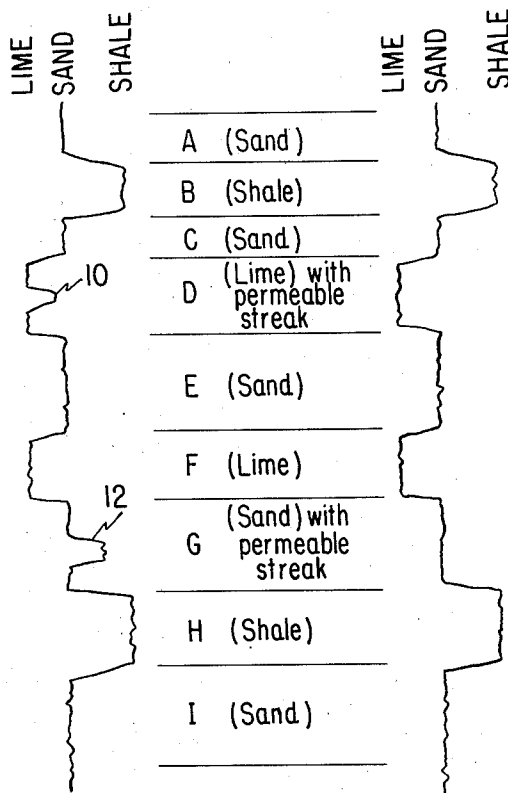
WELL OR BOREHOLE LOGGING

Filed Nov. 12, 1948

2 SHEETS—SHEET 1

FIG. 1

FIG. 2



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2 SHEETS--SHEET 2

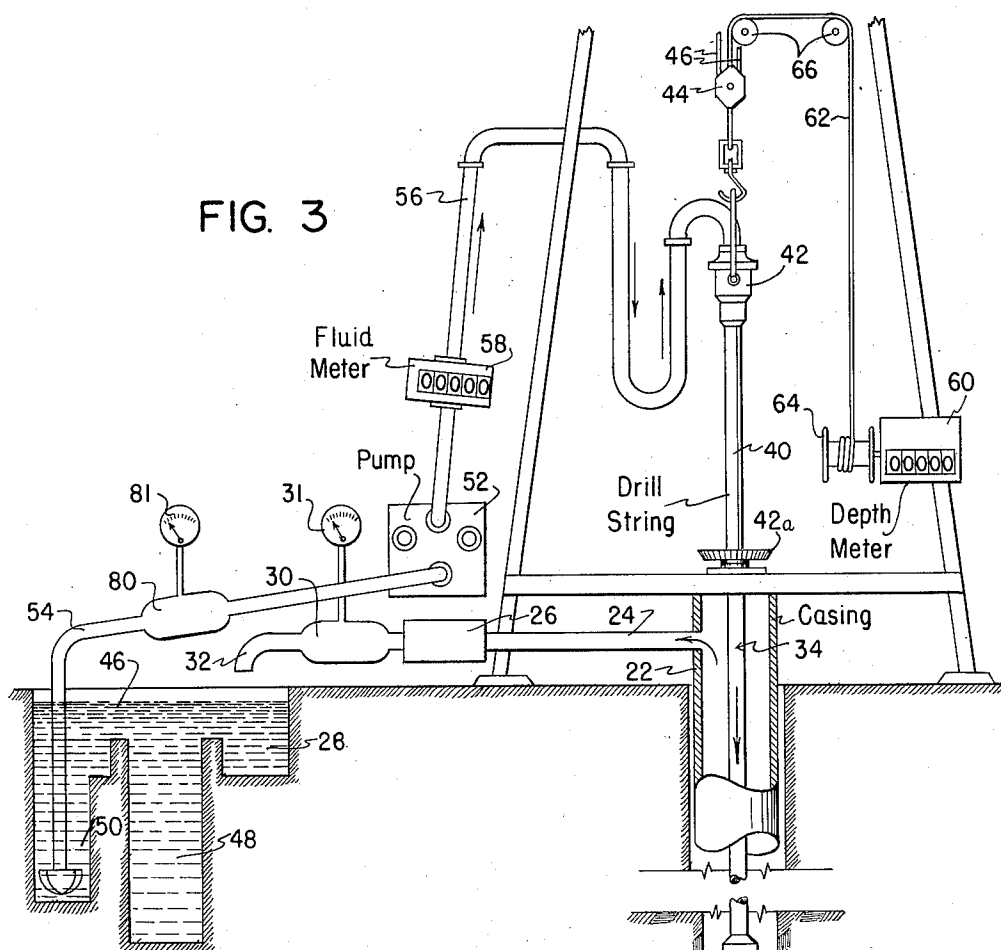


FIG. 4

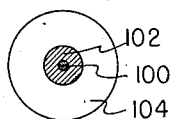
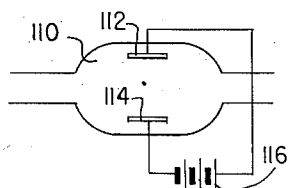
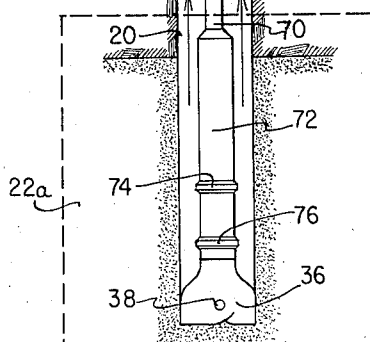


FIG. 5



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UNITED STATES PATENT OFFICE

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WELL OR BOREHOLE LOGGING

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7 Claims. (Cl. 250—83.6)

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The present invention relates to well or bore hole logging and has for its primary object the provisions of new and improved methods and apparatus for obtaining indications of the nature of the earth's structure or formation in the vicinity of the bore hole.

Another object of the present invention is the provision of a new and improved method of well or bore hole logging which comprises injecting a contaminating material into the bore hole and thereafter running time spaced instrumental well logs to determine changes in the resulting contamination.

Another object of the present invention resides in the provision of new and improved methods of and apparatus for obtaining indications of the nature of the earth's structure or formation in the vicinity of the bore hole by conditioning the hole as by changing the radioactivity of the formations and thereafter observing the decay in radioactivity, as by logging the well at spaced time intervals.

A further object of the present invention is the provision of new and improved methods of and apparatus for radiologically conditioning or contaminating the earth's structure in the vicinity of a bore hole in order better to obtain indications of the nature of the earth's structure or formation in the vicinity of the bore hole.

It is known that certain characteristics of the earth's formation, such as permeability and porosity, in the vicinity of a bore hole can be determined by radioactive well logging, as by running a gamma ray log of the bore hole. However, known methods require overriding of the natural radioactivity of the earth's formations by the injection of mud or other carrier of high radioactivity into the bore hole before satisfactory indications can be obtained. This procedure may be dangerous because of the high radioactivity of the mud that must be injected into the bore hole. This difficulty, according to one of the features of the present invention, is eliminated because it does not require the use of an overriding high radioactivity mud.

It is an object of the present invention to provide a new and improved method of well logging in which characteristics of the earth's formation, such as permeability and porosity, are logged by determining the changes in artificially induced contamination of the formation.

A further object of the present invention is the provision of a new and improved method of well logging which comprises running gamma ray well logs at predetermined spaced time intervals and comparing the results to determine the decay in artificially induced radioactivity and thereby determine the permeability and porosity of the subsurface structure.

A further object of the present invention is to provide a new and improved method of well logging in which radioactive mud is first forced

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into the bore hole, the bore hole is then washed with nonradioactive mud, and two time spaced gamma ray well logs are run to determine the relative amounts of radioactivity and obtaining from them an indication of the formation permeability.

A further object of the present invention is to provide a new and improved method of well logging in which a relatively short lived radioactive tracer is released into the mud, as by generation and as an incident to the drilling and then circulated during the drilling process to contaminate the subsurface structure in the vicinity of the bore hole. Then two time spaced gamma ray logs are run to provide time spaced indications of the change in radioactivity from which the permeability and/or porosity can be determined.

Another object of the invention is to provide a new and improved method of well logging in which radioactive tracer is released into the drilling mud by continuous neutron bombardment.

A further object of the present invention is the provision of new and improved methods for radiologically conditioning or contaminating the earth's structure in the vicinity of the bore hole for the purpose of obtaining indications of the nature of the earth's formation by bombarding the formations with a neutron emitting substance.

A further object of the present invention is to provide new and improved methods of and apparatus for obtaining indications of the nature of the earth's structure or formation in the vicinity of the bore hole by injecting a neutron emitting substance into the formations and thereafter logging the hole with an instrument sensitive to neutrons.

A further object of the present invention resides in the provision of new and improved methods for obtaining indications of the nature of the earth's structure in the vicinity of a bore hole by injecting into the bore hole a substance that emits neutrons with a very short half life, waiting for several of these half lives, logging for gamma rays, waiting a period corresponding to several half lives of the expected artificially induced radioactivity and logging again.

Other objects and advantages of the present invention will become apparent from the ensuing description of illustrative embodiments thereof, in the course of which reference is had to the accompanying drawings, in which:

Figs. 1 and 2 are illustrative graphs of time spaced gamma ray logs run in accordance with the invention;

Fig. 3 is a diagrammatic representation of apparatus which can be used in the practice of the invention; and

Figs. 4 and 5 are illustrations of contaminating apparatus made in accordance with the invention.

In practicing the present invention, the well

or bore hole may be contaminated by forcing radioactive mud into the bore hole. In the event the drilling is carried on with the use of conventional nonradioactive mud, a method which can be used is substantially as follows: (1) replace the nonradioactive mud with radioactive mud and force the latter under pressure into the bore hole; (2) wash the bore hole with nonradioactive mud to clean washouts in which radioactive mud may have accumulated during the preceding step (this step is not essential but is preferably used); (3) run a first gamma ray well log; (4) run a second gamma ray well log after waiting for one or several half lives of the radioactive material; and (5) compare the two logs to determine dissimilarities and thus obtain an indication of the formation permeability and porosity.

The gamma ray well logs may be standard radioactivity logs, see "Well Logging by Radioactivity," by W. G. Green and R. E. Fearon, *Geophysics*, vol. V, No. 3, 1940, pp. 272-283, i. e., the well is explored vertically with a radiologic measuring instrument sensitive to gamma rays and a curve is plotted on an automatic recorder which is a usual part of the radioactivity logging apparatus.

The radioactive material can be introduced into the bore hole at any convenient time. This may be upon completion of the drilling operation or after an interesting zone has been drilled. When this occurs, the drilling operation is suspended and the above-described method followed.

The logs indicate the sum of two effects: (1) the natural radioactivity of the rocks, and (2) the radioactivity due to the infiltration of the radioactive fluid into the rock pores.

The results of an exemplary first log are illustrated in Fig. 1 showing the passage through nine zones, A to I, inclusive, comprising sand, shale and limestone, as indicated.

After the passage of a predetermined length of time a second log is run. The results of this log are depicted in Fig. 2. The difference between the deflections along the X axis (horizontal) of the graphs of Figs. 1 and 2 indicates the effect due to the contamination of or the invasion of the radioactive fluid. The differences between the two graphs result from the decay of the artificial contamination, which is present in the graph of Fig. 1, but which has disappeared from the graph of Fig. 2 because of decay with time.

Considering the graphs in detail, zone A is interpretable by standard radioactivity log interpretation as a sand and, since the deflections of the two logs are the same, it can be concluded that no fluid invasion took place and that the sand is nonpermeable. Similarly, zones B and H are interpreted as nonpermeable shale, zones C, E and I as nonpermeable sand, and zone F as nonpermeable limestone. Marked differences are apparent in zone D, there being a sharp peak 10 to the right in Fig. 1. This indicates an increase in radioactivity due to penetration of the radioactive mud into limestone. The zone would, therefore, be interpreted as a porous permeable streak in limestone. Another peak 12 appears in zone G and it is interpretable as a permeable streak in sand.

When the radioactive mud is injected into the bore hole, a certain amount penetrates into the formations in the proximity of the hole. The degree of penetration and the amount of penetration are functions of the permeability and

porosity, respectively. As is well known, porosity is expressed by the percentage of the void space in a solid and in the ordinary rocks it is of the order of 20%. Permeability is a function of interconnection between the pore holes. Consequently, it is possible to have material which is porous but not permeable. Such material will have pore spaces which are not interconnected. As the mud injected into the bore hole invades the formation to a certain distance a certain amount of radioactive fluid will be accepted by the formation and this amount is a function of permeability and porosity. The radioactivity of the fluid accepted by the formation decays with time and it is this decay that is noted.

The radioactive material used preferably has a relatively short life. An extremely short life is impractical because of transportation time from the irradiating plant (atomic pile) to the well location. Cadmium 115 can be used. It has a gamma radiation of approximately .5 m. e. v. and half-life of 43 days. Indium 114, having a gamma radiation of .19 m. e. v. and a half-life of 48 days, can also be used. Using materials of this character requires a wait of four or five months for their activity to decay substantially. Consequently, a relatively long period of time is necessary between the two logging operations. However, during this period, the well can be completely cased and cemented in conventional manner so that no danger of cave-in will exist. The cementing and casing do not prevent the running of the second radioactivity log because the rays penetrate these materials. When a shorter waiting period is desired, radioactive isotopes of shorter half-life may be used, such as radio-iodine 131, which has gamma radiations of 0.367 and 0.08 m. e. v. and a half-life of 8 days and radio phosphorus 32, which has a beta radiation of 1.69 m. e. v. and a half-life of 14.3 days.

The mud can be rendered radioactive in suitable manner. For example, suitable radioactive materials can be added to the mud or the radioactive material can be generated and released into the mud stream above the surface of the ground. A suitable location for generating and releasing the tracer would be in the discharge pipe of a pump circulating the drilling fluid through the bore hole. The discharge pipe can be provided with a suitable chamber 110, as illustrated in Fig. 5. Within the chamber are mounted electrodes 112 and 114 connected to a suitable source of power 116. The electrodes are insulated from the chamber and made of radioactive material adapted electrolytically to dissolve in the mud stream by the current flow thereacross in the manner disclosed in my co-pending applications Serial Nos. 783,280 and 55,301, and as will be described hereinafter. Alternatively, apparatus like that shown in Fig. 4, which will be described hereinafter and which can be inserted into a chamber like pipe 110, can be used.

The present invention may be used advantageously with methods in which a contaminating tracer is released into the mud stream simultaneously with the drilling as an incident of a process of continuous radiologic logging, somewhat in the manner of the methods and apparatus disclosed in my above referred to co-pending applications. In thus simultaneously drilling and releasing the contaminating tracer, a radioactive material having a suitable half-life is

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used. Its half-life is such that it remains in the mud and is recirculated with it through the bore hole and thus injected into the earth's formations. The two time spaced gamma ray logs are preferably run so that the first is obtained immediately after drilling operations have been completed and the second several months thereafter.

An apparatus that may be used is illustrated in Fig. 3. The apparatus here shown is illustrated drilling a well or bore hole 20. The drilling is done in accordance with conventional rotary drilling practice in which a circulating fluid, such as a suspension of clay solids in water and conventionally termed "rotary mud" is used to carry the drill cuttings out of the bore as the drilling proceeds. The upper portion of the bore hole is lined with a surface casing 22 extending, as usual, a comparatively short distance into the hole. A fluid outlet pipe 24 discharging into shale shaker 26 is connected to the upper end of the casing. The shaker separates the formation cuttings carried upward by the drill mud from the drilling mud itself. The latter passes from the shaker 26 to a conventional mud ditch 28 through a radioactivity measuring device 30 and a discharge nozzle 32.

Extending into the bore hole through the casing 22 is a conventional hollow drill string designated generally by the reference character 34 which is connected at its lower end to a drill bit 36 having openings 38 adjacent its cutting edges. A Kelly joint 40 is connected to the upper end of the drill pipe and extends through a rotary table 42a mounted on the floor of a derrick. Rotation of the table 42a effects rotation of the Kelly joint 40 and drill string 34 to rotate the bit 36. The upper end of the Kelly joint is connected to the usual rotary hose swivel 42 and the entire drill string assembly is suspended from a traveling block 44 adapted to be raised and lowered in the derrick in conventional manner by means including a cable 46.

The apparatus for circulating the drilling fluid through the well bore comprises the mud ditch 28, a settling pit 48, a pump suction pit 50, and a mud pump 52 connected by a suction pipe 54 to the suction pit and by a discharge pipe 56 to the drill pipe.

The volumetric flow of mud flowing through the discharge pipe 56 may be measured by a fluid meter 58 of conventional type. The depth of the well may be measured by any conventional method. This is commonly done by adding together the measurements of lengths of all sections of drill pipe in the well and by suitable marking of the Kelly to determine how much of it has descended into the well. However, depth measurement can be made by other suitable means, such, for example, as by a depth meter 60 operatively connected by a measuring line 62 to the traveling block. The meter end of the line is connected to a measuring pulley 64 and the other end passes over pulleys 66 to the traveling block.

The lower portion of the drill string 34 includes a drill collar 70, a portion of which is covered with an insulated sleeve 72 to the exterior of which are secured a pair of electrodes 74 and 76, which in accordance with my previously referred to copending applications may include cadmium 115 or indium 114 and are adapted to release a radioactive tracer material into the mud stream in quantities indicative of the conductivity or resistance of the

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earth's formation in the vicinity of the electrodes. The electrodes are, as fully disclosed in my copending applications, supplied with voltage and are made of materials adapted electrolytically to generate and release radioactive material incorporated in one or both of the electrodes.

It is apparent from the foregoing that as the drilling progresses the drill collar with its radioactive releasing electrodes is lowered into the bore hole. Radioactive material is continually emitted into and circulates with the mud stream. In accordance with the present invention, the radioactive material is not removed from the mud stream but is recirculated through the bore hole with the result that the earth's formation in the vicinity of the bore hole is injected with or invaded by the radioactive substance. The amount of penetration of the formations by radioactive mud is dependent upon the permeability and porosity of the formations, as previously described. With the passage of time and continuous drilling, the walls of the bore hole are more or less permeated with the radioactive material. Then either upon completion of the drilling or whenever desired, a pair of time spaced gamma ray logs as previously described are run in order to ascertain the decay in radioactivity in the time between the two logs. This, as heretofore also indicated, provides information regarding the permeability of the subsurface formations.

If desired, the bore hole can be cleaned of the radioactive material by washing it with a neutral fluid as described in connection with the first described embodiment of the invention. Alternatively, if the half-life of the radioactive material is sufficiently short so as to reduce the radioactivity substantially to zero when the second log is run, the mud can be left in the bore hole.

In the last-described embodiment of the invention it is desirable to include radioactive materials in the electrodes which have a relatively short life. The materials may be cadmium 115 or indium 114, iodine 131, or phosphorus 32.

It may be noted, therefore, that the radioactive tracer may be injected into the bore hole during the process of continuous radiologic logging while drilling and may actually constitute a by-product of that method. The infiltration into the formation takes place right at the bit and before serious mudding off has taken place, and is, therefore, superior to methods in which radioactive tracer is forced in after a mud cake has formed. The use of short-lived tracers is particularly advantageous because it makes it possible readily to distinguish between the natural radioactive materials which are, by reason of their existence, of very long half-life, and injected tracer material, which has a short life. This difference in half-life provides the necessary means for differentiating between the two types of radioactivity in the time spaced logs.

The mud and bore hole can also be contaminated simultaneously with the drilling by generating a radioactive tracer material in the drill collar by bombardment with neutrons. The neutrons may be derived from a portable source carried in the drill collar and comprising an intimate mixture of about 1 curie of radium salt with about 15 or 20 grams of finely ground beryllium. Other sources of neutrons may be used, such, for example, as any energetic alpha ray emitter mixed with beryllium powder. In Fig. 4

there is illustrated one arrangement that can be used. It includes an artificial radioactive source that is maintained activated continuously by neutron bombardment. It comprises a central core 100 of radium salt and beryllium powder. This core is surrounded by paraffin 102 which serves to slow the neutrons to such an extent that a preponderance of them are so-called thermal or slow neutrons. The outer surface of the paraffin is covered with a coating 104 of substance to be activated and maintained activated by continuous neutron bombardment. This substance may be phosphorus 32 with gamma rays of 1.51 m. e. v. and a half-life of 12.4 hours; gold 198 having gamma rays of .44 m. e. v. and a half-life of 2.7 days; chromium 51 having gamma rays of .32 m. e. v. and a half-life of 26.5 days.

In accordance with a further feature of the invention the circulating or drilling mud can be contaminated with a neutron emitting substance. In this method, neutron emitting materials are mixed with the mud and circulated through the bore hole. For example, the neutron emitting substance may be in the form of very small particles each consisting of a neutron emitting core covered with a paraffin coating. The neutron emitting core of each particle may comprise radium salt or polonium salt intermixed with beryllium oxide. Then a pair of time spaced gamma ray logs are run, preferably after injection and washing of the bore hole as in connection with the first described method. In this case the log corresponding to the contaminated condition, i. e., the first of the two logs, indicates a variable which is a function of a property of the formation. The property that enters into the log is not very definite but can broadly be described as "neutronic." The neutronic rocks can be recognized and thus detected by their ability to slow down neutrons, capture them, become radioactive and emit gamma rays with a certain energy and a certain half-life which are characteristic of the rock in question. Correlatable logs can be obtained which will show the neutronic rocks as a function of depth and can be compared from well to well giving valuable information regarding the geologic structure of the subsurface.

Instead of injecting a radioactive tracer into the bore hole as in connection with the first of the methods described herein, a neutron emitting substance can be injected into the well. Timed spaced logs with an instrument sensitive to neutrons are then run. This process is very similar to the first-described process, except that neutrons are used entirely.

A substance emitting neutrons with a very short half-life can be injected into the bore hole. A time equal to several of the half-lives of the neutrons is permitted to elapse, after which a gamma ray log is run. After a second period corresponding to several half-lives of the expected artificially induced radioactivity, a second gamma ray log is run. The difference between the last two logs is indicative of the radioactivity artificially induced by the neutrons.

While different embodiments of the invention have been described, it should be understood that various modifications may be made therein which are within the true spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. A method of logging a bore hole or well which includes injecting into the bore hole a neutron emitting substance capable of contam-

inating the earth's formation in the vicinity of the hole, and thereafter running a pair of neutron responsive logs spaced in time relative to the injection to obtain information regarding characteristics of the earth's formation.

2. A method of logging a bore hole or well which includes circulating mud containing a neutron emitting substance under pressure into the bore hole, washing the bore hole with neutral mud, running a first neutron responsive well log, waiting a time interval, running a second neutron responsive well log, and comparing the two logs to obtain information regarding characteristics of the earth's formation in the regions of the bore hole.

3. A method of logging a bore hole or well which includes circulating mud containing a neutron emitting substance under pressure into the bore hole, washing the bore hole with neutral mud, running a first gamma ray well log, waiting a time interval, running a second gamma ray well log, and comparing the two logs to obtain information regarding characteristics of the earth's formation in the regions of the bore hole.

4. A method of logging a bore hole or well which includes mixing a neutron emitting substance with the fluid introduced into the bore hole; and thereafter running a gamma ray well log of the bore hole.

5. A method of logging a bore hole or well which includes mixing with the bore hole fluid a neutron emitting substance capable of contaminating the penetrated formations surrounding the bore hole; permitting the neutron emitting substance to contaminate the said penetrated formations from said fluid; and thereafter running a gamma ray log of the bore hole to obtain thereby a measure of the gamma ray radioactivity induced by said neutron emitting substance in said formations.

6. A method of logging a bore hole or well which includes mixing with the bore hole fluid a neutron emitting substance capable of contaminating the penetrated formations surrounding the bore hole; and thereafter running a first gamma ray log of the bore hole; permitting a time interval of at least one half-life of the neutron emitting substance to lapse following said first gamma ray log; and then running a second gamma ray log of the bore hole, thereby to obtain the difference between the gamma ray radioactivities of the first and second gamma ray logs, as a measure indicative of the radioactivity artificially induced in the materials of said contaminated penetrated formations.

7. A method of logging a bore hole or well which includes mixing a neutron emitting substance with the fluid introduced into the bore hole; and thereafter running a plurality of time spaced gamma ray measurements in the bore hole.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,339,129	Albertson	Jan. 11, 1944
2,358,945	Teichman	Sept. 26, 1944
2,364,975	Heigl et al.	Dec. 12, 1944
2,385,378	Piety	Sept. 25, 1945
2,390,931	Fearon	Dec. 11, 1945