April 1, 1952 S. KRASNOW ET AL 2,590,874

MULTIPLE ELEMENT RADIOACTIVE RAY RECORDING

Filed July 24, 1942 8 Sheets-Sheet 1

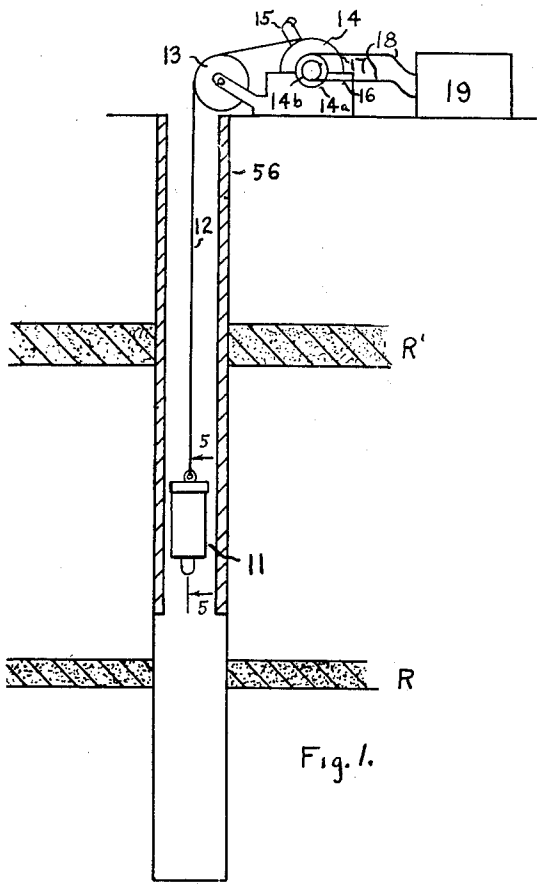


Fig. 1.

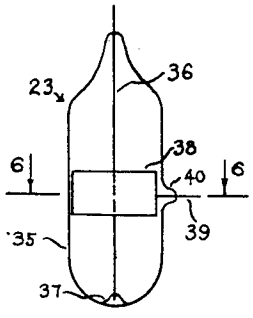


Fig 3.

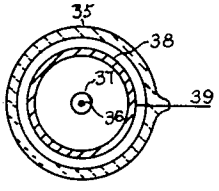


Fig. 4.

INVENTORS
SHELLEY KRASNOW,
LEON F. CURTISS,

By Shelley Krasnow

ATTORNEY

April 1, 1952 S. KRASNOW ET AL 2,590,874

MULTIPLE ELEMENT RADIOACTIVE RAY RECORDING

Filed July 24, 1942 8 Sheets-Sheet 2

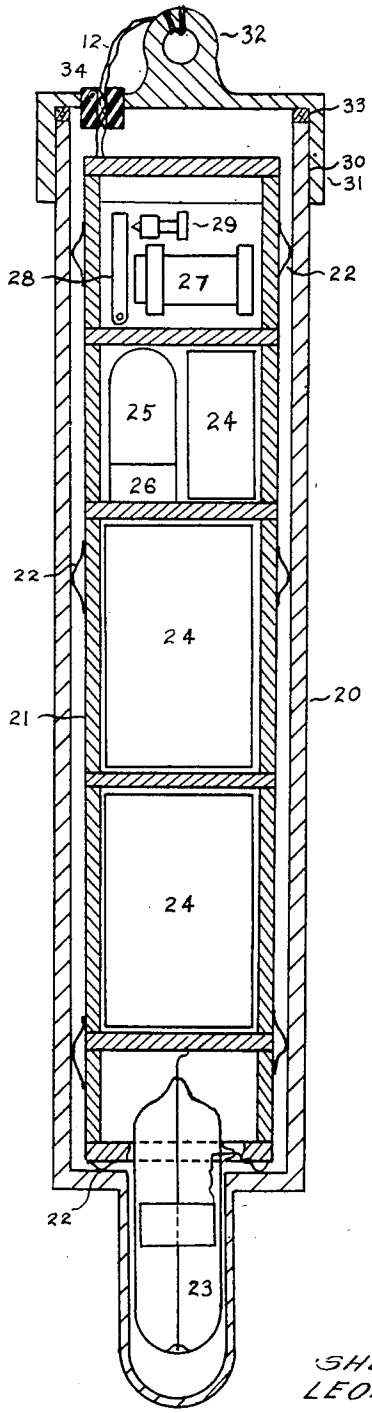


Fig. 2.

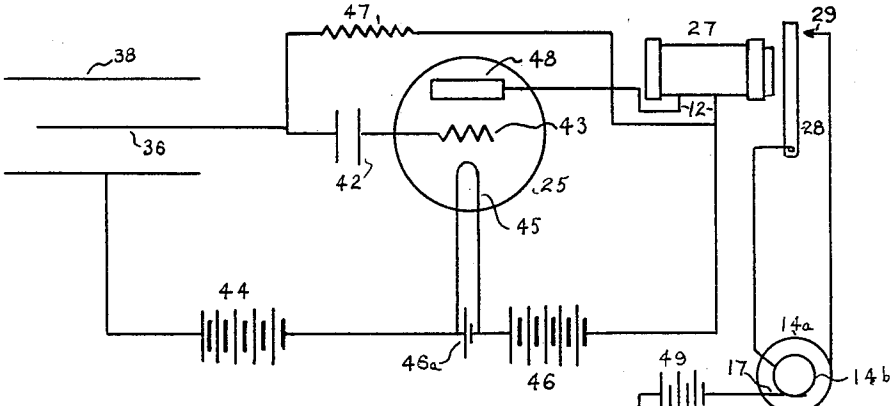
INVENTORS
SHELLEY KRASNOW,
LEON F. CURTISS,
Shelley Krasnow
ATTORNEY

April 1, 1952 S. KRASNOW ET AL 2,590,874

MULTIPLE ELEMENT RADIOACTIVE RAY RECORDING

Filed July 24, 1942 8 Sheets-Sheet 3

Fig. 5.



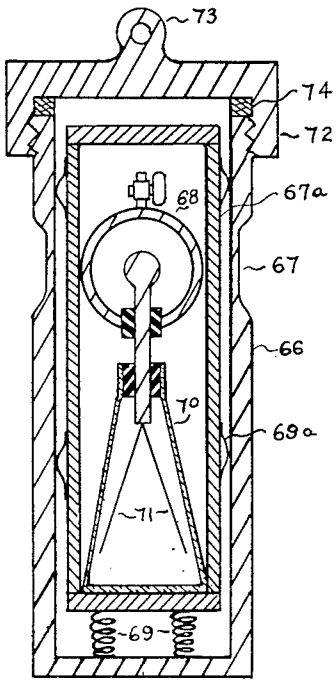


Fig. 6.

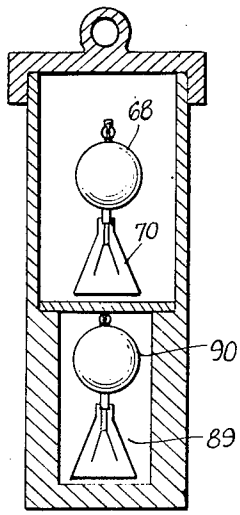


Fig. 7.

INVENTORS
SHELLEY KRASNOW,
LEON F. CURTISS,

By Shelley Krasnow

ATTORNEY

April 1, 1952 S. KRASNOW ET AL 2,590,874

MULTIPLE ELEMENT RADIOACTIVE RAY RECORDING

Filed July 24, 1942 8 Sheets-Sheet 4

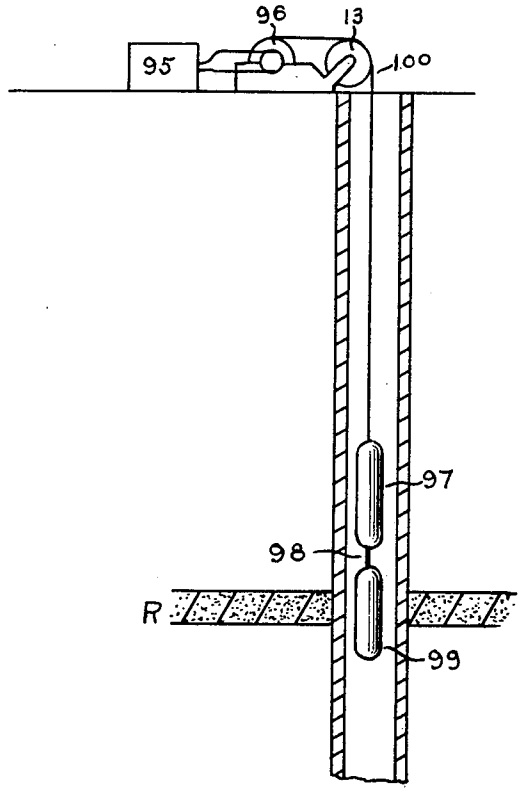


Fig. 8.

INVENTORS
SHELLEY KRASNOW,
LEON F. CURTISS,

By Shelley Krasnow
ATTORNEY

April 1, 1952 S. KRASNOW ET AL 2,590,874

MULTIPLE ELEMENT RADIOACTIVE RAY RECORDING

Filed July 24, 1942 8 Sheets-Sheet 5

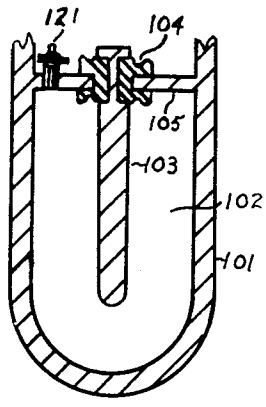


Fig. 10.

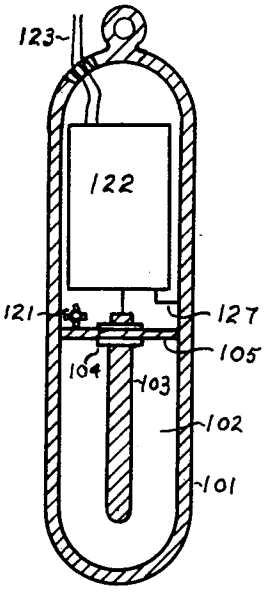


Fig. 9.

INVENTORS
SHELLEY KRASNOW,
LEON F. CURTISS,

By Shelley Krasnow,

ATTORNEY

April 1, 1952 S. KRASNOW ET AL 2,590,874

MULTIPLE ELEMENT RADIOACTIVE RAY RECORDING

Filed July 24, 1942 8 Sheets-Sheet 6

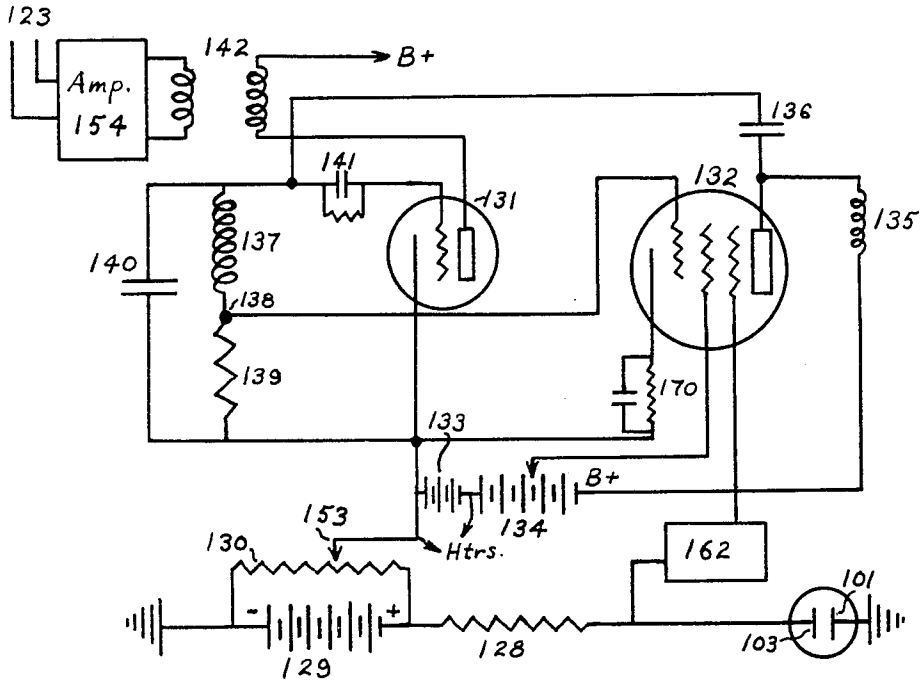


Fig. 11

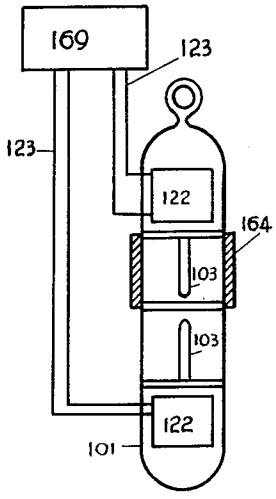


Fig. 15.

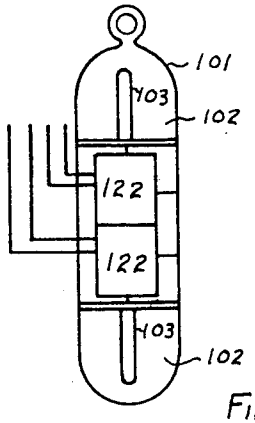


Fig. 12.

INVENTORS
SHELLEY KRASNOW,
LEON F. CURTISS,
By Shelley Krasnow
ATTORNEY

April 1, 1952 S. KRASNOW ET AL 2,590,874

MULTIPLE ELEMENT RADIOACTIVE RAY RECORDING

Filed July 24, 1942 8 Sheets-Sheet 7

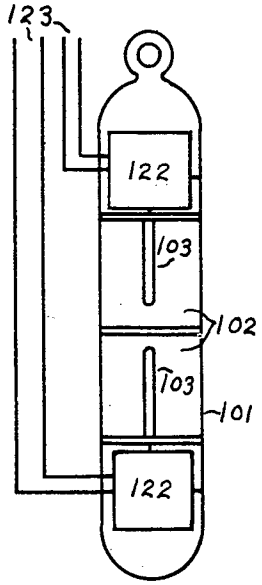


Fig. 13.

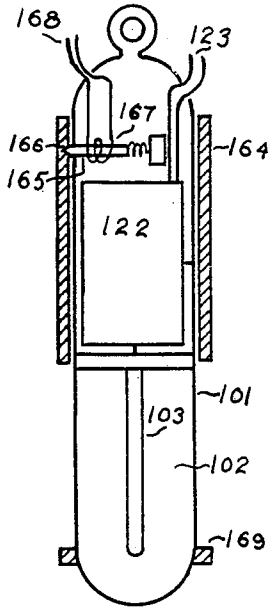


Fig. 14.

INVENTORS
SHELLEY KRASNOW,
LEON F. CURTISS,
By Shelley Krasnow
ATTORNEY

April 1, 1952 S. KRASNOW ET AL 2,590,874

MULTIPLE ELEMENT RADIOACTIVE RAY RECORDING

Filed July 24, 1942 8 Sheets-Sheet 8

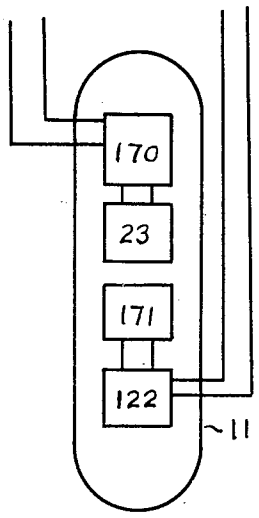


Fig. 16

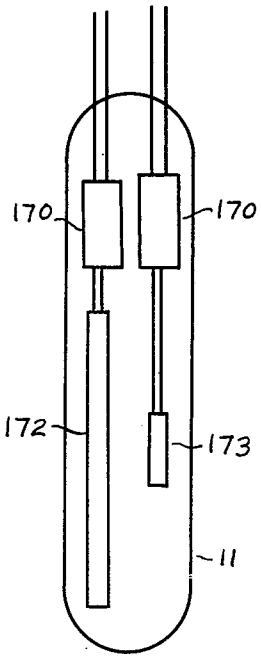


Fig. 17

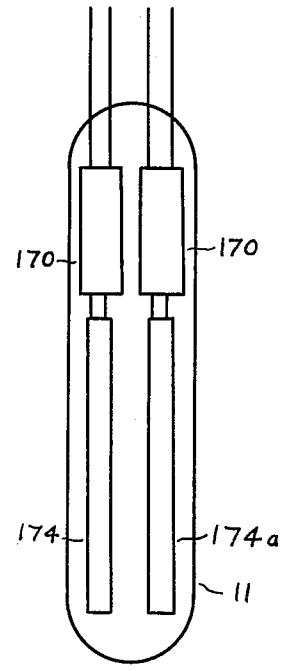


Fig. 18

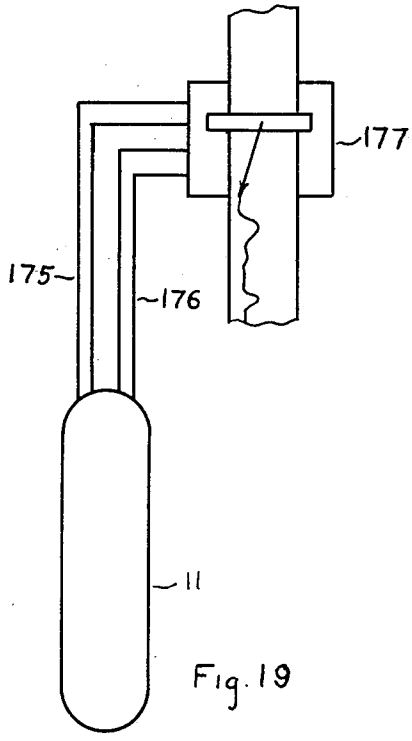


Fig. 19

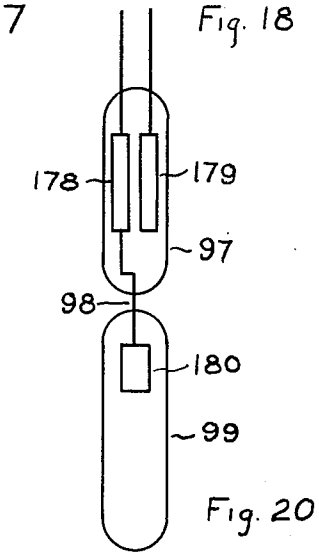


Fig. 20

Inventors

Shelley Krasnow

Leon F. Curtiss

By Shelley Krasnow

Attorney

Patented Apr. 1, 1952

2,590,874

UNITED STATES PATENT OFFICE

2,590,874

MULTIPLE ELEMENT RADIOACTIVE RAY RECORDING

Shelley Krasnow, Arlington County, Va., and Leon F. Curtiss, Montgomery County, Md., assignors to Schlumberger Well Surveying Corporation, Houston, Tex., a corporation of Delaware

Application July 24, 1942, Serial No. 452,228

5 Claims. (Cl. 250—83.6)

1

This invention relates to an improved method and apparatus for measuring radioactivity, and has particular reference to a method and apparatus for measuring radioactivity in inaccessible locations, such as in boreholes or at considerable depths in bodies of water.

One object of the invention is to provide a method and apparatus useful for locating deposits of minerals having radioactive properties. Another object of the invention is to provide an apparatus by which one may measure radioactive properties continuously from the top to the bottom of a borehole, and have both an immediate indication, and a permanent record, of the radioactivity at various depths.

In locating deposits of radioactive minerals it is often the custom to drill a number of boreholes in localities where such deposits might exist. It is further the practice to bring samples or cores of the drilled material to the surface of the earth, and there examine them for radioactivity by well known methods and apparatus. This method has several drawbacks. First, a deposit of ore may exist close to the borehole, but not be traversed by it, by which the deposit will be missed. Second, it is possible to make an error in ascertaining the exact depth from which a core or sample has been taken. Finally, it is rarely possible to bring all of the core to the surface, a certain percentage always being lost in the drilling or handling.

It is further known that deposits of petroleum are often markedly radioactive as compared with the surrounding rock material. This is believed to be due to the superior absorptive property of petroleum for radium emanation. Natural gas and ground water are also known to be somewhat more radioactive than their surrounding rock material. In drilling for either petroleum or natural gas, or ground water, it is desirable to know the exact level at which the strata having these are traversed by the drilled hole. This is often difficult to determine, particularly when drilling has been done by the "rotary" method, in which the use of mud under pressure tends to wall off the strata. Often too, the drilled hole will be lined with a metallic casing, which casing by accident or intention may seal off strata having the desired fluid.

It is the intention in the present invention to provide an apparatus so sensitive, and a method appropriate to its use, that the relatively faint radioactivity of oil and ground water may be detected in place in a borehole. An apparatus sensitive enough to serve this function will by its

2

nature differentiate between the different though faint radioactivities of the rock material. Rock materials, dependent upon their origin and dependent upon the minerals contained in them, have different radioactivities. Thus, it has been found that granite, shales having organic materials embodied therein, sedimentary rocks containing zircon, and rock materials having mica associated with them, are all slightly more radioactive than for example limestone or chalk deposits. Sandstones will differ in their natural radioactivity, depending upon the minerals contaminating them. Organic deposits, such as coal, oil and natural gas, as mentioned above, petrified vegetable matter, etc., will show higher radioactivities than for instance limestone and chalk. Thus, with an apparatus as sensitive as that described herein it will be possible to differentiate between different layers of rock by the differences in their radioactivities. Each layer in an area will have a characteristic radioactivity, just as it has a characteristic chemical compostion, and for the same reason. Thus, the radioactivity of a layer will serve as a variety of marker, serving to identify the layer wherever it might be in an area.

It thus becomes possible to identify rock layers in different bore-holes drilled in an area and thus correlate the strata.

Further objects of the invention described are to obviate the difficulties mentioned and secure the advantages mentioned above.

Reference is had to the accompanying drawings in which:

Figure 1 shows a more convenient form of apparatus for measuring radioactivity at various depths in a borehole.

Figure 2 shows a cross sectional view of the element 11 shown in Figure 1, taken across the plane 2—2.

Figure 3 shows the sensitive element employed in the apparatus shown in Figure 2.

Figure 4 shows a cross section of the element in Figure 3 taken across the plane 3—3.

Figure 5 shows the circuit diagram of the apparatus shown in Figure 1.

Figure 6 shows a vertical cross sectional view of still a further type of apparatus which may be used for the purpose described.

Figure 7 shows essentially the same apparatus as is shown in Figure 6 with the addition of another electroscope to serve as a control.

Figure 8 shows a modification of the apparatus designed to permit perforation of the casing in a well.

Figure 9 shows another type of apparatus for measuring radioactivity at various depths and giving an immediate indication at the surface of the ground of the value of the radioactive intensity.

Figure 10 shows a detail of the lower portion of the apparatus shown in Figures 14 and 15.

Figure 11 shows the electrical circuit suitable for use in the modification shown in Figure 9.

Figure 12 shows an apparatus for measuring radioactive gradient.

Figure 13 shows a modification of the apparatus indicated in Figure 12 to render measurements of radioactivity more dependable.

Figure 14 shows an apparatus for measuring radioactive intensity with the interposition of a filter.

Figure 15 shows an apparatus with plural measuring elements, one of the elements being provided with a filter.

Figure 16 shows an arrangement of plural elements, in which both a Geiger-Müller counter and an ionization chamber are employed.

Figure 17 shows an apparatus to be lowered into a borehole, consisting of two Geiger-Müller counters of different size.

Figure 18 shows an apparatus adapted to be lowered into a borehole, having two Geiger-Müller counters, each of different characteristics.

Figure 19 shows an apparatus employing plural elements, with recording provided at the surface of the earth for the composite response of the two elements.

Figure 20 shows a plural radioactive measuring element employed in conjunction with a perforator.

A more convenient form of the apparatus shown in Figure 5 employs a cartridge 11 suspended in the borehole by a conducting cable 12. The cable 12 passes over a measuring wheel 13 and thence onto a reel 14 operated by a crank 15. A pair of slip-rings 14*a* and 14*b* fastened to the shaft of the reel 14 have bearing upon them the brushes 16 and 17. These brushes are connected through the medium of wires 18, 18, to a recording element 19. Referring now to Figures 2 and 3, the cartridge 11 consists essentially of a radioactive-sensitive member 23 mounted at the bottom of a pressure-tight cartridge 20. A rack 21 holds the element 23 and serves further to hold batteries 24, vacuum tube 25, and relay 27. Springs 22 serve to prevent violent contact of the frame 21 with cartridge 20. A cap 31 is fastened by means of a threaded or other connection 30 onto one end of cartridge 20. A fluid tight seal is had by the use of gasket 33. The wires necessary to convey the signals from the cartridge 11 pass through insulating bushing 34 and are looped onto ring 32 and thence pass to the surface. In this way the wire serves also for raising and lowering member 11.

The sensitive element 23 consists essentially of a sealed glass vessel 35 which has within it a conducting ring 38 connected to wire 39 passing through seal 40. Through the axis of ring 38 there passes another conducting member 36, in the form of a wire or filament. This member 36 passes through seal 41 and is further anchored against mechanical movement by being fastened to the bottom of the vessel at 37. Container 35 is filled with any desired gas such as air, at a pressure which may be as little as a few centimeters of mercury or as much as atmospheric, and is then sealed off, after which it may be used for long periods of time without further attention. In operation the members 36 and 38 are kept at a high potential relative to each other by means of batteries 46 and 44 operating through high resistance leak 47, as shown in Figure 5. A suitable value for the voltage of battery 46 is 135 volts; of battery 44, 360 volts. The positive end of battery 44 is connected to one side of the filament 45 of vacuum tube 25. The member 36 is connected to a blocking condenser 42 and thence to the grid 43 of the same vacuum tube. The plate 48 of this tube is connected through relay 27 to the positive end of battery 46. The relay 27, when de-energized, serves to close contacts 28 and 29, thus allowing a current to flow through wires 12, slip-rings 14*a* and 14*b*, brushes 16 and 17, electro-magnet 50 and battery 49. The electro-magnet 50 serves to attract armature 51 which further serves to move pen 52 across the tape 53 kept in constant uniform motion by means of drum 54 operated by driving means 55.

The operation of the apparatus is as follows: The members 36 and 38 are charged at a controlled rate to a high potential relative to each other by means of the batteries 46 and 44 operating through leak 47. In the presence of radioactive material the gas in the container 35 will be partially ionized and will thus change the potential of the member 36. This will result in a change of potential of the grid 43 which will reduce the current normally flowing between filament 45 and plate 48 of vacuum tube 25. This will in turn reduce the current in relay 27 sufficiently to allow its armature 26 to be retracted, closing the circuit between member 28 and contact 29. The closing of this circuit will cause a current to flow through slip-ring 14*b*, brush 17, battery 49, electro-magnet 50, brush 16, and slip-ring 14*a*. The energizing of electro-magnet 50 will cause armature 51 to move pen 52, causing a break in the line traced on tape 53.

Upon the operation of the circuit in this fashion, the potential of member 36 will be restored to its original value, increasing the filament-to-plate current in tube 25, energizing relay 27 and thereby causing the circuit made by members 28 and 29 to open.

Upon the further ionization of the gas in container 35 the operation above described will be repeated. Thus the frequency of the pulses finally received by pen 52 will be a measure of the radioactivity of the material in the vicinity of member 23. It will be noted that the rays given off by radioactive substances have considerable penetrating power and can therefore easily penetrate the shield 20 even if the latter be made of metal. To reduce the absorption of these rays by the metal, however, that portion of the cartridge 20 which houses the member 23 is provided with thinner walls than the remainder; a construction made possible by the smaller diameter of the said portion. It will be noted further that even if a metallic casing such as 56 exists in the borehole the presence of a radioactive layer such as R' may be noted because of the easy penetration of the rays through the thickness of metal ordinarily employed for casing.

Another type of apparatus which may be employed is shown in vertical cross section in Figure 6. In this, cartridge 66 is provided with a threaded cap 72 sealed by gasket 74 and raised and lowered by ring 73. Within the cartridge 66 is a frame 67*a* which holds an ionization

chamber 68 connected to an electroscope 70, which may be of any suitable type, but which is shown schematically as a gold leaf electroscope employing leaves 71. Springs 69 serve to cushion the shocks imparted to the frame 67*a*. A circumferential thin portion 67 of the cartridge is provided to reduce the absorption of the rays in passing to the chamber 68. In use the electroscope is charged to a high potential relative to the outer walls of the ionization chamber 68. It is then mounted on frame 67*a*, inserted in cartridge 66, the latter sealed with cap 72, and the whole lowered into the well. The apparatus is allowed to remain at a depth where presence of radioactive material is suspected, for a suitable length of time. It is then raised and the alteration in charge on the electroscope noted. A second electroscope similar to electroscope 70 may be mounted in the cartridge 66 and shielded from radiation, to serve as a control. Thus, the cartridge 66 may be made longer and an electroscope and ionization chamber, entirely shielded with lead, mounted above the chamber 68. This arrangement is shown in Figure 7, the control electroscope and ionization chamber being designated respectively as 89 and 90.

In the type of apparatus shown in Figure 2 the chronograph and entire recording system may be clock operated and mounted in the cartridge so that no conducting wires need pass to the surface. As a further alternative the motion of the tape may be made not a function of time, but rather of the position of a measuring wheel such as 13.

Another apparatus which may be used for the same purpose is shown in Figure 9. This consists of a cartridge 101, which is provided with a gas-tight partition 105 and a gas-filled space 102. Located preferably centrally within the space 102 is an electrode 103, carefully insulated by means of amber or other low leakage insulating material 104. In the partition 105 is mounted a valve 121 by which gas may be introduced to attain any desired pressure within the enclosure 102, after which the valve 121 may be shut and the said pressure maintained. The wall 101 is made of strong material, as thin as possible to reduce the absorption of rays of radioactive material passing into the space 102. A material which will combine strength and transparency to rays from radioactive substances is utilized. Suitable materials are: magnesium alloys, aluminum alloys such as duralumin, beryllium, or beryllium alloys. A very thin steel housing may be used, the greater strength allowing the material to be so thin that absorption is not serious. The space 102 may be filled with any one of a number of gases. A suitable gas for this purpose is nitrogen, although other gases may be used with almost equally good results.

It is of advantage to rib or corrugate the surface of the insulation as shown, to increase the leakage path. Although element 121 is shown as a valve, in practice it may be advantageous to use a standard type of sealed-off glass joint, as employed in the glass blowing art.

The pressure in the ionization chamber is preferably higher than atmospheric so as to give a greater ionization current, as will be familiar to those versed in the art. A pressure of several hundred pounds per square inch will be found suitable. The voltage across the chamber is made as high as possible so as to obtain an increased ionization for a given change in intensity of ionizing rays. The voltage is limited, however, by the fact that if it is made too high, ionization by collision will result and the chamber will support a steady discharge regardless of the intensity of ionizing rays in its vicinity. The value of the resistance is such as to cause an easily measurable voltage drop across its terminals for the usual intensity of ionizing rays. Its value will be chosen with regard to this and with regard to the requirements of the voltage indicating device. Good results may be obtained with a resistance having a value comparable and preferably approximately equal to the effective resistance of the ionization chamber. Suitable values are: a battery voltage of 130, and a resistance value of 10 megohms.

In the modification shown in Figure 9, the information is transmitted to the surface through wires 123, allowing immediate observation at the surface, as well as recording. The central electrode 103 of the ionization chamber is connected to element 122 which represents schematically the electrical apparatus more fully shown hereinafter. A lead 127 is connected to metallic casing 101 serving to ground certain of the elements employed in the apparatus 122. Leads 123 extend to the surface of the ground, where they may pass over a wheel such as 13, onto a reel such as 14 provided with slip rings such as 14*a*, and 14*b*. Connecting wires such as 16 and 18 serve to connect to frequency measuring apparatus, substituted for element 19 shown in Figure 1.

Referring now to Figure 11, 101 and 103 represent the elements of the ionization chamber. The side 101 is grounded, while the electrode 103 is connected to one terminal of a high resistance 128. The other terminal of resistance 128 is connected to the positive end of a high voltage battery 129, the negative end of this battery being grounded. A potentiometer 130 is connected across the terminals of battery 129, with its movable contact 153 connected to the cathode of a triode vacuum tube 131. A lead joins electrode 103 and the grid of a pentode vacuum tube 132. While a pentode is shown in the specific embodiment disclosed, any multi-element tube having three or more elements, and having the proper characteristics, may be used.

A conventional battery 133 is shown to provide the heater current for the tubes. A "B" battery 134 is shown connected to battery 133 and leading to choke 135, the other terminal of the choke being connected to the plate of tube 132. A tap is taken off battery 134 to provide the screen grid voltage for tube 132. The plate of tube 132 is connected through condenser 136 to inductance 137. Inductance 137 terminates at terminal point 138 to which is connected one end of resistor 139. The other end of resistor 139 is connected to contact 153 as shown.

Across inductance 137 and resistance 139 is placed a condenser 140. The common terminal point 138 is connected to a grid of vacuum tube 132. While connection to a specific grid has been indicated, it is also possible to connect a lead from terminal 138 to the cathode of tube 132 or to any other element except the plate of the same tube, with satisfactory results. It will be understood that proper biasing means will be utilized for the specific type of tube chosen.

The cathode of tube 132 is connected through a conventional self-biasing arrangement 170 to the contact 153. The grid of tube 131 is connected through a conventional self-biasing arrangement 141 to inductance 137. The plate of tube 131 is connected to the primary of a cou-

pling transformer 142, the other end of the primary being connected to the "B" battery as shown. The secondary of coupling transformer 142 may be connected to leads which are brought directly to the surface of the borehole and which are connected to a suitable frequency or other measuring device such as 19. A suitable frequency can be chosen, high enough to be easily measurable, and low enough to avoid difficulties due to capacity and inductance effects along the transmitting cable.

The coupling transformer may be connected to an amplifier such as 154, the amplifier feeding into the external cable as shown. The amplifier will be found particularly valuable in preventing external load variations from reacting on the principal circuit and thus causing a disturbing change of frequency.

While Figure 11 discloses an apparatus for generating a frequency in proportion to the intensity of radioactivity, it will be understood that an apparatus utilizing phase shift or amplitude variation as a function of radioactive intensity, may be used instead of one employing frequency variation.

An amplifying stage 162 may be inserted in the lead from element 103 of the ionization chamber to the grid of tube 132. This will be a direct current amplifier, and will serve to increase the voltage change on the grid for a given change in potential on element 103. Where the change in potential on element 103 is sufficient to cause a proper voltage change of the grid, the amplifier 162 may be omitted, and a direct connection made between the lead 103 and the grid element.

The operation of the circuit may be described as follows: The elements 137, 139, and 140, together with tube 131, biasing arrangement 141 and the proper "A" and "B" voltage supplies, constitute an oscillatory circuit whose natural frequency is dependent on the values of inductance 137, condenser 140, and resistance 139.

There will be an alternating voltage across the terminals of resistance 139, which voltage will be in phase with the current flowing through the resistor. This voltage will be impressed between the cathode and one grid of tube 132, and will cause in general an alternating voltage of the same frequency between the grid and plate of tube 132. The voltage across resistor 139 is 90° out of phase with that across 137. Consequently, the voltage impressed by vacuum tube 132 across inductance 137 will also be 90° out of phase with the voltage in inductance 137. The magnitude of this voltage will be dependent upon the amplification due to tube 132. Any out-of-phase voltage across inductance 137 will have the effect of changing the apparent value of the inductance and will thereby cause a change in the frequency generated by the oscillatory circuit.

Any increase in radioactive intensity will alter the effective resistance between the electrodes 101 and 103. Through the agency of battery 129, an increased current will flow through the circuit composed of battery 129, resistance 128, and electrodes 101 and 103. This increased current will cause a greater voltage drop between terminals of resistance 128, which increased voltage drop, after amplification by amplifier 162, will be impressed across the cathode and a grid of tube 132. If the screen grid voltage has been properly adjusted, any change in the potential of the grid connected to amplifier 162, will cause a change in the effective amplification factor of tube 132. This change, as described previously will cause a change in the out-of-phase voltage impressed across inductance 137 and will thereby cause a change in the natural frequency of the oscillatory circuit described herein. The alternating current flowing through inductance 137 will induce voltages of equal frequency in transformer 142 and consequently in amplifier 154.

It is therefore seen that an alteration of radioactive intensity will cause a related and functionally connected change in frequency in the output of amplifier 162.

The voltage of battery 129 should be so chosen as to obtain the maximum ionizing effect without actual breakdown, and the value of resistance 128 should be of such value as to cause a significant voltage change across the cathode and grid of tube 132. The values of the constants in the remainder of the circuit should be chosen so that with the voltage changes normally obtained across the cathode and grid of tube 132, a sufficient change in frequency will be obtained in the output.

While a variety of vacuum tubes may be used for elements 131 and 132, a suitable set will be had by using an RCA type #957 tube as element 131 and an RCA type #959 tube as element 132. Suitable values for the other elements are as follows:

129—135 volts
134—135 volts
128—10 megohms
170—1800 ohms and .01 mf.
136—.002 mf.
137—700 microhenries
140—20 mmf.
141—50,000 ohms and .0005 mf.
139—100 ohms

As described herein, the frequency may vary over a wide range, depending upon the particular mode of transmission of information to the surface. A suitable frequency is one megacycle.

Figure 12 shows an apparatus which may be utilized to measure what may be termed as the radioactive gradient along the length of a borehole. This apparatus is comprised of elements such as shown in Figure 10 in duplicate, and mounted at a substantial axial distance from each other. Each unit is connected to its associated measuring circuit 122, the outputs of the two circuits being each connected to separate frequency measuring systems at the surface of the ground. The two frequency measuring systems may be interconnected so as to superpose one frequency on the other and give the difference of the two frequencies as a result. In this way a measure will be obtained of the relative radioactivity of the rock materials at the respective levels of each of the ionization chambers. Thus the gradient or rate of change of radioactivity may be detected.

This modification will permit further distinguishing the actual radioactivities of the strata from the possible individual erratic behavior of each of the measuring elements.

If the latter feature is sought rather than the actual measurement of gradient of radioactivity, the measuring elements may be placed close together and their combined effect noted.

This modification is shown in Figure 13.

Figure 14 shows a modification of the apparatus shown in Figure 9, suitable for measurement of radioactive intensity through a filter. It will be understood that in certain areas little contrast will be noted in radioactive intensity throughout

the length of the borehole. Advantage may be taken of the fact that different radioactive materials emit rays having different distributions of intensity in the radioactive spectrum. Thus, if a layer in the borehole is contaminated with thorium, the total intensity recorded on the apparatus may be the same as that for a layer contaminated with radium. However, if measurements be taken with a filter, the intensity due to radium will appear greater than that due to thorium, and the difference may be noted. The filter may also be found particularly valuable in cases where radioactive material is used as an indicator, as will be hereinafter described. Different materials may be introduced in the borehole, each having different radioactive properties. They may later be identified by measurements taken with a filter.

The apparatus shown in Figure 14 resembles that shown in Figure 14, except that an outer cylindrical shield or filter 164 has been placed completely surrounding the cartridge 101. A latch 165 is held by a spring in an indentation 166 in the filter. This latch may be operated by a solenoid 167 actuated by wires 168 which pass to the surface of the borehole. On passing an energizing current through wires 168, solenoid 167 will cause latch 165 to be withdrawn from indentation 166, allowing filter 164 to drop till it strikes the circumferential stop 169.

With filter 164 in the raised position, the apparatus will operate as previously described. The only filtering action will be that of the cartridge, and which is intrinsic in the material used. If it is desired to make the measurement with a filter, the energizing current can be applied while the apparatus is in the borehole, which will cause the filter to assume an operative position, after which a further measurement can be taken. With the filter 164 against stop 169 all rays entering the ionization chamber radially will have to pass through the filter. Since most of the rays enter the chamber in this way, the equivalent of a nearly complete filter will be obtained.

The filter may be made of any metal or substance having the desired absorbing properties. Examples of suitable materials are copper, lead aluminum, etc. It is understood that the filter may be incorporated with the cartridge 101, and be made permanent, in which case only the filtered rays will impinge on the instrument.

There will be a special advantage in the utilization of the filter about one of the units shown in Figure 12 or 13. Here a differential result will be obtained, giving to the observer the difference between the filtered and unfiltered rays. Alternatively, filters may be used about both of the elements shown in Figures 12 and 13, a different filter being used about each element. By successive runs, with different pairs of filters, the data collected will be of greater value than that obtained by the mere measurement of unfiltered radiation.

Figure 14 shows an apparatus similar to that shown in Figure 13 with the addition of a filter 164 about the upper ionization chamber 103. Duplicate leads 123, 123, conduct the amplified responses from elements 122, 122 to apparatus 169 at the surface of the earth. Element 169 constitutes means for comparing the two frequencies from elements 122, 122. It will be noted from the description of the function of element 122 given herein, particularly as to its operation as shown in Figure 11, that each element 122 will give an output frequency related to the intensity of radioactivity as measured by its respective member 103.

The apparatus shown in Figure 2 particularly, may be made extremely sensitive to the rays emitted by radioactive substances and so the sometimes faint radioactivity of petroleum, natural gas, and ground water detected. As has been pointed out previously, this may be done in spite of any covering of mud or of metallic casing intervening between the walls of the borehole and the cartridge 11. It is in fact, possible to run the cartridge 11 inside of the standard drill pipe used in rotary drilling and thus make measurements with a minimum of disturbance to drilling. Because of the limited absorptive power of the metals customarily used for drilling, it will be possible to detect radioactive rays through the thickness of metal in the drill pipe, or even through the several inch thickness of the drilling tools.

While, from what has been disclosed above, it is evident that strata may be differentiated from each other by means of the quantitative difference in the amount of associated radioactive material, it will be appreciated that strata need not necessarily be widely different in their associated radioactivity to enable one to differentiate them from one another. In cases where the associated radioactivities are not conspicuously different in conducting measurements from one end of the bore hole to the other, valuable information may still be obtained by considering the manner in which the radioactivity varies, or phrased differently, the function by which radioactive intensity changes as the depth is altered. This will be found particularly valuable in searching for oil deposits. It will be recalled that petroleum deposits in the natural state have water associated with them. In many cases the water underlies the petroleum, and will have a radioactivity markedly different from that of the petroleum itself. Thus if an apparatus as described above, were lowered past a formation, a sudden change would be observed in passing from rock to petroleum, another sudden change in passing from petroleum to water, and still another sudden change in passing from water to rock. The layers might thus be easily identifiable despite the fact that their radioactivity may be no greater or less than that of most of the rock lining the borehole.

It is obvious that any other means than those shown or described may be used to convey the frequency of the impulses produced by the apparatus in Figure 2, to the surface.

The elements employed in the member 11 may be combined with a perforating tool as ordinarily used for perforating casing in oil, gas or water wells. With this it will be possible to lower the apparatus slowly until an indication of radioactivity is received. The apparatus may then be stopped and the perforating procedure carried on as usual. This will have the advantage of eliminating the inaccuracy usually made in measurement. Heretofore, it has been the custom to measure the depth to the level in question, then run the perforator to that depth. This involved two measurements, the combined error of which was at times sufficient to cause perforation to be performed at the wrong level. The method described above can have none of these errors, since it is not dependent in any way on a measurement of depth.

A schematic showing of this appears in Figure 8. Here an apparatus capable of measuring radioactivity is shown schematically as 97. This is connected to a perforating element 99. This latter arrangement may be of any of the well known types. However, the type known as a "gun perforator," which perforates the casing by firing bullets through the casing, will be found particularly suitable. The assemblage made up of radioactive apparatus 97, connector 98 and perforating element 99 may be raised and lowered by means of cable 100. This cable will serve both for raising and lowering and for operating the apparatus and making observations. The cable passes over wheel 13, onto reel 96. Connection is made between the reel and apparatus 95. Apparatus 95 serves to make observations and to control the elements that are being raised and lowered.

It will be noted that one of the fundamental concepts here involved is that of utilizing plural elements which may be lowered as a unit, and which will furnish simultaneous responses. A number of useful modifications may be constructed utilizing this principle. A number of representative modifications are given below, it being understood that these are not limiting but rather exemplary. Thus, advantage may be taken of the different behavior of different types of radioactive measuring elements. For example, one element may be a Geiger-Müller counter with the proper associated circuit, while the other element may be an ionization chamber with the proper associated circuit. The responses from each of the members may be transmitted separately to the surface of the earth and there recorded in correlation with depth. Although both pieces of apparatus mentioned are subject to extraneous disturbances, the disturbances will in general not occur at the same time nor will they be of the same nature or pattern. Thus, only those responses which are common to both members need be recognized.

This is shown schematically in Figure 16. Here, a cartridge 11, adapted to be lowered within the borehole has within it a Geiger-Müller counter 23, together with its associated circuit 170. This associated circuit is the equivalent of that shown for instance in Figure 5. It will give at its output a response proportional to the radioactivity acting upon the Geiger-Müller counter. Similarly, an ionization chamber 171, similar to that shown in Figures 9 and 10, is placed within the same cartridge 11. This has its associated circuit 122, described in detail previously, together with leads going to the surface of the earth.

Similarly, a Geiger-Müller counter and ionization chamber may be utilized, one apparatus utilizing high voltages fed from the surface of the earth, the other utilizing high voltage supplied by batteries lowered with the sensitive member. Or two Geiger-Müller counters or two ionization chambers may be utilized, one of the two operating from voltages supplied from the surface of the earth. Still further, plural elements may be utilized, one type of circuit being utilized for one element, another type of circuit utilized for the other. Thus, one circuit may be responsive, for instance, to temperature and may have temperature enter as a factor in the results. The other circuit may be responsive, for instance, to vibration and have the effects thereof enter as a factor into the results. The use of both circuits simultaneously allows one to correct or compensate for that portion of a record obtained under adverse conditions for a given circuit, having at all times a usable record from at least one circuit or the other. It will be obvious that the probability of the same disturbance arising in both circuits to the same extent due to different causes is exceedingly small, so small that it may in practice be neglected.

Thus, the arrangement as shown in Figures 12 and 13 may be utilized, the two elements 122, 122, having been indicated above.

Still another use which may be made of plural elements would involve the conjoint use of short and of long elements sensitive to radioactivity mounted adjacent each other, and provided with separate amplifying and transmitting apparatus. A short element (either a Geiger-Müller counter or an ionization chamber) will distinguish thin layers readily, but is not very efficient for the rapid logging of relatively weak formations. On the other hand, a long counter is less capable of discriminating and resolving thin layers while acting efficiently for rapid logging of weak formations. The use of the two elements operating and recording simultaneously allows one to operate rapidly for certain portions of a borehole, and to slow down operations for other portions. In the first case, the responses from the large measuring element would be given chief attention, while in the latter case the small element would enable one to indicate position of a layer with greater accuracy. This modification is also highly useful for the location of radioactive markers, whether natural or artificial. The large measuring element may be utilized while lowering the apparatus rapidly, to find the approximate position of the radioactive markers. Such an element, being larger, will in general be more sensitive and can detect the marker at a greater distance and with a greater speed of lowering. Once the approximate position has been obtained, the small element can be utilized to locate the position of the marker with certainty. It is understood that when large and small elements are referred to, they may be different as to diameter or different as to length or both, or they may have differences in their physical structure which will cause them to act respectively as large or small elements. Or the two elements may be different, one having a greater sensitivity of response than the other, due to treatment of the active surfaces, the circuit involved, etc. This is shown schematically in Figure 17, 11 being the enclosing cartridge lowered into the earth as before. A large Geiger-Müller counter is shown together with its associated circuit 170, with leads going to the surface of the earth. Similarly, there is provided a small Geiger-Müller counter and associated circuit 170, with leads going to the surface of the earth.

Similarly, plural elements may be utilized one responsive chiefly to hard gamma rays, the other chiefly to soft gamma rays. Or one element may be made sensitive particularly to neutrons, while the other element is sensitive chiefly to gamma rays. As for example, a Geiger-Müller tube with a cylinder of rhodium, silver, or metal associated or lined with boron compounds will respond readily to neutrons, while a tube with a copper cylinder will respond primarily to gamma rays and will be little affected by neutrons. Where both neutrons and gamma rays are expected, such plural elements allow the simultaneous detection. Since neutrons are often given off by sources which also emit gamma rays, a log of neutron intensity is made far more certain by a concomitant

log of gamma ray intensity. This is shown schematically in Figure 18, in which the enclosing cartridge is 11, a Geiger-Müller counter of one type, 174, connected to its associated circuit 170, with leads going to the surface of the earth, and another Geiger-Müller counter 174a placed within the same enclosure has its associated circuit 170 with its leads going to the surface of the earth. Thus, as before, separate indications will be transmitted upward separately, and may be received and detected separately.

It will be understood that any one of the measuring systems shown herein may be utilized for measuring with one element, while any of the other systems shown herein may be utilized for the other element, or that both elements may have the same sensitive members and transmitting systems.

Another use of the plural elements will be where the response from one of the plural elements will actuate some mechanism such as a gun perforator. The method of doing this has been fully described in our co-pending application, Serial No. 438,475. Since such an element need be responsive only to strong sources, and might have an auxiliary actuating system which affects the accuracy of results obtained thereby, it will be found desirable to utilize this element for actuating purposes only, while utilizing a separate element to transmit responses to the surface. Both elements may, however, be actuated from the same power source, so that one will act as a pilot element indicating that the system is functioning, while the other will serve only for automatic actuation. The basic arrangement is shown in Figure 8, and the details thereof in Figure 20. Here two elements responsive to radioactivity are provided, identified as 178 and 179. Element 178 serves to actuate apparatus 180, which in turn operates the gun perforator. Element 179 is the pilot element, indicating that the system is functioning.

It will be understood that each measuring element may furnish a separate trace on a chart, produced either photographically or with a pen, this chart being if desired a single one whose movement is proportional to the position of a measuring sheave. The responses from both members may, however, be fed into a single recording galvanometer or pen recorder, which will then give the sum of the responses from the members. Thus, one obtains a record which is automatically made proportional to the average integrated response from the members. This is shown schematically in Figure 19, pairs of leads 175 and 176 leading upward from cartridge 11. Both of these leads 175 and 176 feed into a single recording galvanometer 177, which serves to record the combined response.

This case continues and extends the teachings of our co-pending applications Serial No. 137,380 and 301,078.

The scope of the invention is defined by the appended claims.

We claim:

1. In a method of investigating radioactivity in a bore hole drilled into the earth, the steps of simultaneously lowering into the bore hole a plurality of radiation responsive devices having different radiation response characteristics, exposing said devices to radioactivity in the bore hole so as to cause at least one of said devices to respond significantly thereto, and obtaining indications of the responses of said devices whereby information about radioactive conditions in the bore hole may be obtained by comparing the indications of the responses of said devices.

2. In a method of investigating radioactivity in a bore hole drilled into the earth, the steps of simultaneously lowering into the bore hole a plurality of radiation responsive devices, shielding at least one of said devices from radioactivity originating externally thereof, exposing said devices to radioactivity in the bore hole so as to cause at least one of said devices to respond significantly thereto, and obtaining indications of the responses of said devices, whereby information about radioactive conditions in the bore hole may be obtained by comparing the indications of the responses of said devices.

3. In a method of investigating radioactivity in a bore hole drilled into the earth, the steps of lowering into the bore hole a radiation responsive device of given radiation response characteristics, exposing said device to radioactivity in the bore hole so as to cause it to respond significantly thereto, obtaining indications of the response of said device, lowering into the bore hole another radiation responsive device of different radiation response characteristics, exposing said other device to radioactivity in the bore hole in the same manner as said first device, and obtaining indications of the response of said other device, whereby information about radioactive conditions in the bore hole may be obtained by comparing the indications of the responses of said devices.

4. In apparatus for investigating radioactivity in a bore hole, the combination of a plurality of radiation responsive devices having different radiation response characteristics mounted for movement through the bore hole in fixed relation to one another, and means for providing indications of the responses of said devices.

5. In apparatus for investigating radioactivity in a bore hole, the combination of a plurality of radiation responsive devices mounted for movement through the bore hole in fixed relation to one another, means for shielding at least one of said devices from radioactivity originating externally thereof, and means for providing indications of the responses of said devices.

SHELLEY KRASNOW.
LEON F. CURTISS.

REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
2,097,760	Failla	Nov. 2, 1937
2,133,776	Bender	Oct. 18, 1938
2,197,453	Hassler	Apr. 16, 1940
2,275,456	Neufeld	Mar. 10, 1942
2,285,840	Scherbatskoy	June 9, 1942
2,296,176	Neufeld	Sept. 15, 1942
2,303,683	Fearon	Dec. 1, 1942

OTHER REFERENCES

"Geophysics," vol. IV, pp. 106 to 114, March 1939.