

Oct. 16, 1956

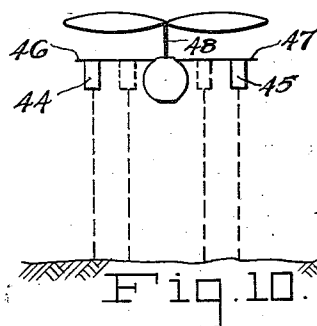
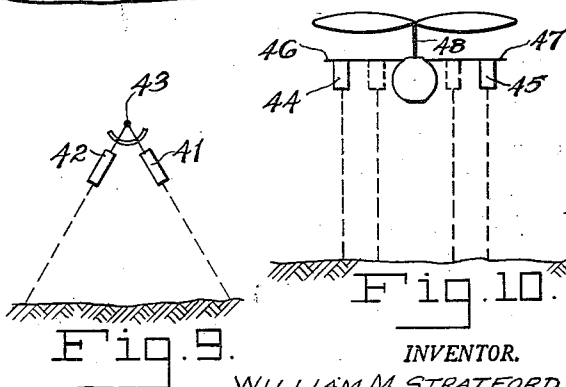
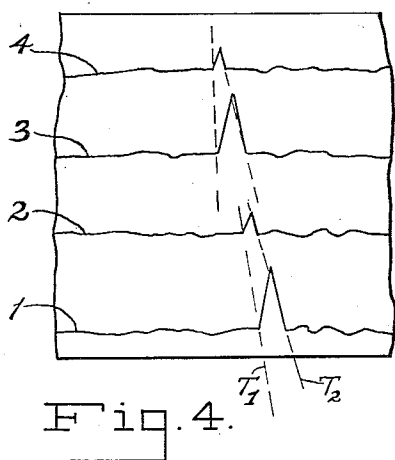
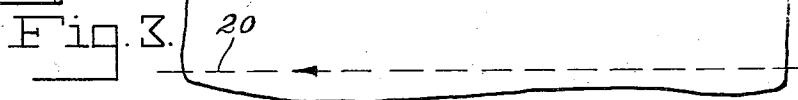
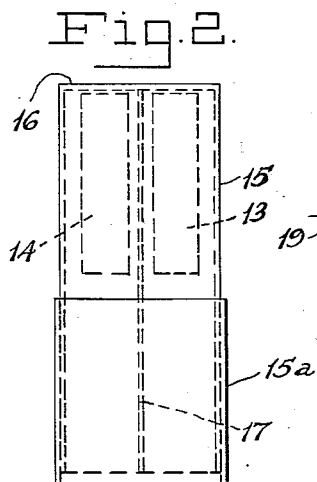
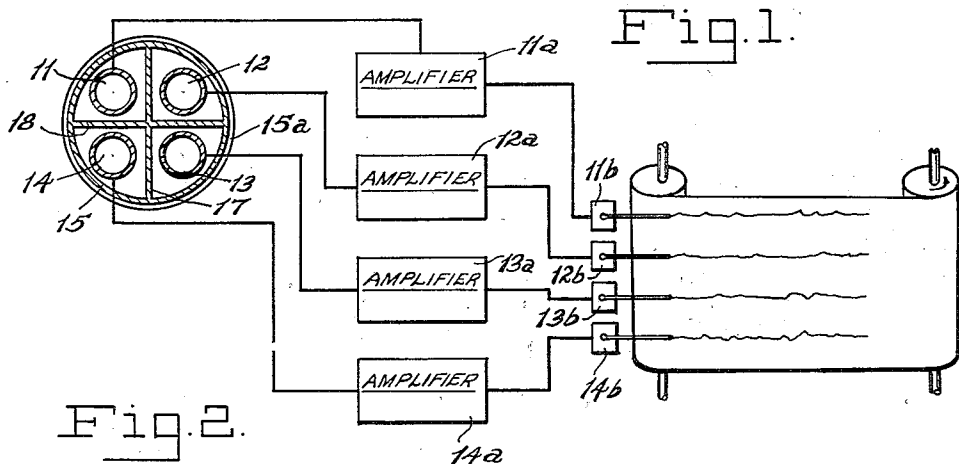
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2,767,326

RADIOACTIVE EXPLORATION

Filed May 21, 1952

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

Fig. 6

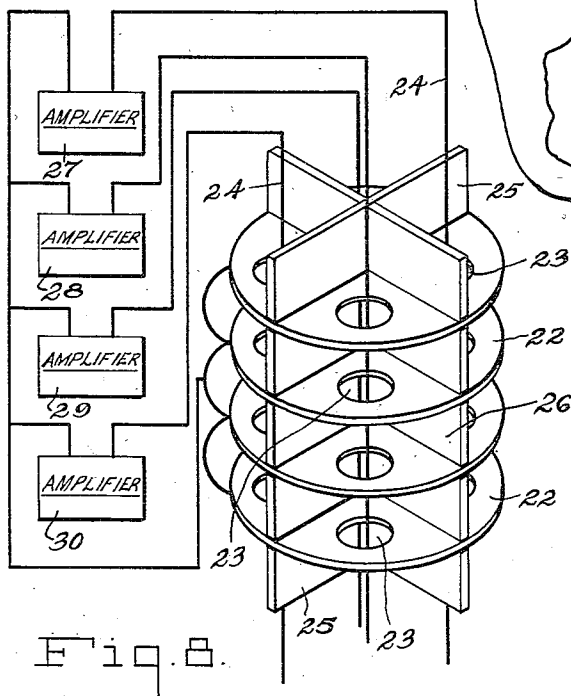
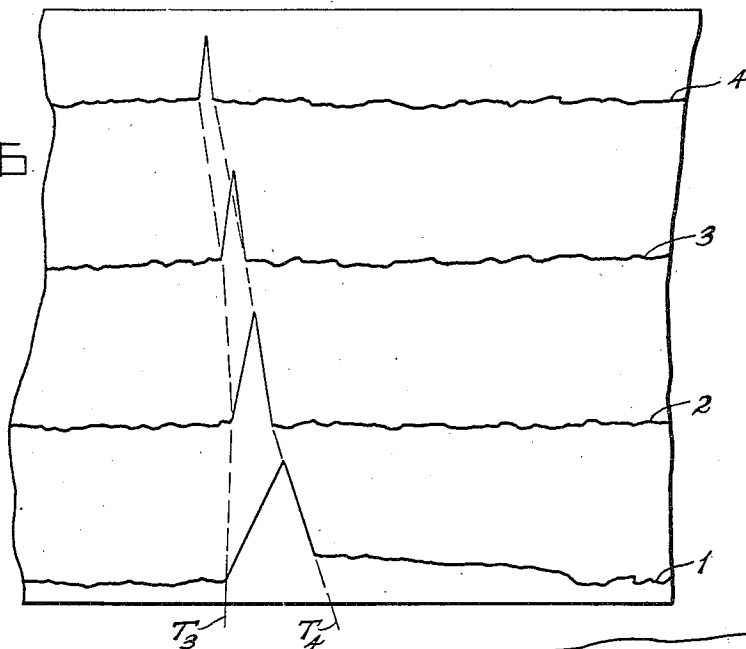


Fig. 8

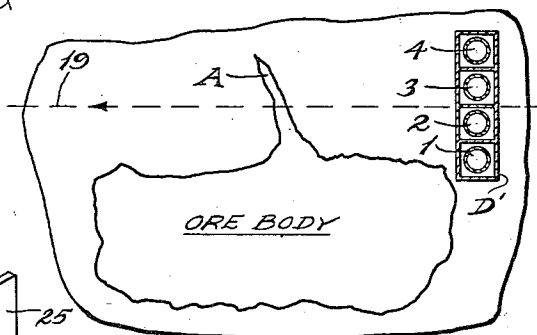


Fig. 5

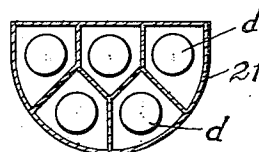


Fig. 7

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3 Sheets-Sheet 3

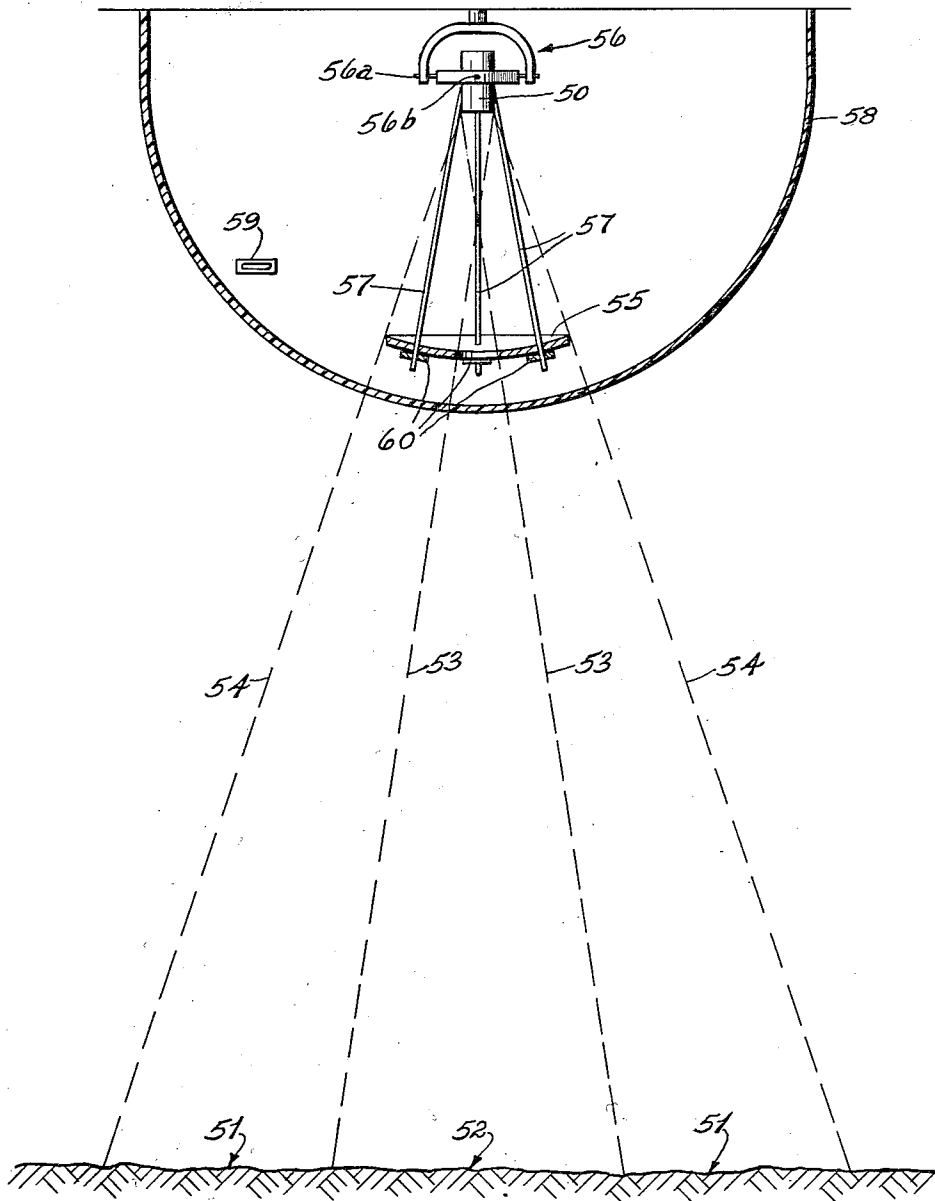


Fig. 11.

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RADIOACTIVE EXPLORATION

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Application May 21, 1952, Serial No. 239,091

7 Claims. (Cl. 250—83.6)

This invention relates to prospecting for mineral deposits in the surface of the earth, and more particularly to prospecting by radioactive detection.

This application is a continuation-in-part of my U. S. patent application Serial No. 62,347 which was filed on November 27, 1948, now abandoned.

The principle of radioactive detection has been utilized in the past in prospecting for strongly radioactive minerals such as those containing uranium or radium, to provide direct and positive indications of exposed deposits thereof. In such prospecting, portable Geiger-Mueller counters are moved along the ground surface in regions in which experience indicates the possibility of such deposits, and the counting rate is observed. The presence of a strongly radioactive deposit, if it is not buried too deeply, will be evidenced in some such way as by an increase in the detector's counting rate. Since this prospecting is in predetermined localized regions the detection apparatus can be carried on the backs of the operators or on slow pack animals. Where a deposit is buried beneath a large amount of overburden, so much of the radiation emitted by it may be absorbed that significant variations therein are obscured.

In the U. S. Patent 2,562,914 which issued to Gerhard Herzog on August 7, 1951, a method is disclosed wherein such deeply buried deposits, and even deep deposits of certain non-radioactive ores, can be located indirectly by detecting significant variations in the intensity of gamma radiation emitted by the overburden (or "country rock") rather than by the deposit itself, preferably by the use of radiation detectors, such as those of the multiple-plate type (see Hare Patent No. 2,397,071, issued March 19, 1946), or scintillometers, or groups ("banks") thereof, which have gamma ray counting efficiencies well in excess of those of conventional Geiger-Mueller counters.

Whether the detector means or head used in either of the above-mentioned forms of prior art prospecting comprises a single detector or a so-called bundle thereof, it customarily is sensitive to radiation approaching it from a large, not precisely-defined zone, such as a large area of the earth's surface surrounding a vertical projection thereon of the vehicle carrying the detector, and it provides but a single record of intensity variations. Its non-directional sensitivity results from the fact that customarily the detector is exposed, as indeed it may be without detriment to accomplish the purposes for which it is intended in such types of prospecting, to all radiation approaching it from the earth over a very large solid angle, such as one of substantially 2π . Its inability to provide more than a single record results from the fact that, even when a number of detectors (a so-called "bundle"), is used, they are not individually shielded to prevent radiation which floods one of them, after approaching it over a given solid angle, from also flooding one or more of the others, e. g., they all receive radiation from the same area of the earth's surface. Accordingly it has been customary to connect them all to a single recorder.

The present invention is concerned with using radioactivity prospecting for other purposes in addition to locating specific deposits within regions previously localized in other ways, such as by mining experience, geological studies, etc., and its value in all such prospecting is based on recognition of the limitations of the prior art practices of using non-directive detectors and of making only one record.

One particularly important purpose for which radioactivity prospecting can be used is to obtain data from which one may plot "contour" lines or "isoradins" designating regions on a map where "natural" emissions of radiation have discrete respective densities, e. g., average, $x\%$ above average, $y\%$ below, etc. This information can be correlated with other kinds of information available to geologists to help them in localizing regions in which detailed prospecting may be carried out in any suitable way, for example by the two kinds of radioactivity prospecting first mentioned above. While this kind of information can certainly be developed for localities containing areas of highly concentrated radioactivity, due, for example, to deposits containing uranium and/or radium, it can also be developed for areas in which the only radiation encountered is the weak "natural" radiation emitted by the traces of radioactive materials which are so sparsely distributed everywhere in the earth's constituents that they are not otherwise detectable. Moreover while this information will certainly be helpful in localizing regions wherein strongly radioactive deposits are likely to occur (and perhaps it may even serve to pin-point the deposits themselves), it will also be helpful, though in a less obvious way, in localizing regions which are likely to contain non-radioactive minerals such as metallic ores, petroleum, etc.

However in order to obtain this kind of information the detector or detector means whether it be of the single or multiple detector type must be able to perceive, i. e., "resolve," radioactivity anomalies which may be manifested by small-magnitude intensity-changes and may occur in relatively small areas of the terrain being surveyed. Such resolution cannot be achieved by successively exposing the detector to radiation emanating from large areas of the earth's surface since a small-magnitude anomaly occupying a small area cannot appreciably increase or diminish the total radiation from a large area including it. Thus the presence of a physically invisible geological "fault," which could be evidenced by a small but definite difference in the intensities of natural gamma radiation emitted by the earth's solids on each side of the fault, might pass undetected if the prospecting is done with a detector which receives all of the radiation from a large area at any one instant.

Incidentally since this type of radioactivity prospecting is in the nature of a reconnaissance to be conducted over wide areas, it cannot be rapidly practiced by using an operator or a slow-pack animal for carrying the detector. Preferably though not necessarily this type of prospecting should be carried out as an aerial survey. However, as the detector is carried to greater and greater heights, the ground area from which radiation approaches it over a fixed solid angle of exposure rapidly increases while at the same time the radiation is attenuated en route in accordance with the inverse square law.

Accordingly radioactivity prospecting as it has been practiced in the past is not to be preferred for this survey type of radioactivity prospecting since the first of its above-mentioned limitations makes it difficult to perceive, i. e., to "resolve," radiation anomalies which consist of small magnitude changes in the intensities of the radiation emanating from small adjacent areas on the ground. Incidentally it is noted that the perception of small-area anomalies may have great value, in addition to its value

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in the preparation of contour maps of the kind described above, as direct clues to the presence of types of strongly radioactive ore bodies which may often extend for considerable distances at easily workable depths below the surface but have one or perhaps a few surface out-croppings which are so small as to be detected only by apparatus having good resolving power.

Therefore according to one of the features of the present invention the detector's zone of sensitivity is restricted to a small solid angle having its apex near the detector means and its base on a ground area small enough to afford the required resolving power.

However two practical difficulties are encountered in carrying out air-borne radioactivity prospecting with a detector having directional sensitivity: (1) the aircraft must fly a greatly increased number of courses to cover a given area since the strip of the terrain covered in flying a single course is greatly reduced; (2) it is much more difficult for the pilot in flying successive courses to maintain parallelism with the same percentage of accuracy; and (3) changing aspects of the plane due to banking, climbing, descending, etc. will swing the detector's lobe of sensitivity away from normalism with the ground thus altering the lobe's directivity and the length of the radiation path along it from the ground.

Accordingly it is a principal object of this invention to provide a novel method of radioactivity prospecting whereby anomalies in the surface of the earth, even of very limited areas, may more readily be determined.

Another object is to provide radiation detection apparatus capable of detecting small-area radiation anomalies at the surface of the earth even when the apparatus is airborne and operating at relatively high altitudes.

It is still another object to provide radiation detection apparatus which may have directional sensitivity and be transported aboard an aircraft without incurring the three difficulties mentioned above.

Still a further object, particularly in aerial surveys, is to avoid any restriction to a limited range of altitudes and to enable such surveys to be conducted at any reasonable altitudes while still maintaining the desired discrimination with respect to small areas of the ground, thus taking advantage of detectors of increased sensitivities.

According to the present invention the resolving power needed in order to be able to detect the radiation emanating from a small ground area is attained by using a detector having an associated collimating-shielding means for restricting its zone of sensitivity to a relatively small solid angle having its apex in the radiation-sensitive portion of the detector and its base on said area; the first two of the difficulties mentioned above are averted by carrying more than one collimated detector on the same aircraft so that in each flight over a single course a plurality of terrain strips are surveyed simultaneously and the strips in question are accurately parallel to each other; and the last difficulty is averted by using flexible mounting for each detector in such a way that, despite tilting and dipping of the plane and the like, the detector's narrow lobe of sensitivity is always pointing in the same downward direction.

In the drawing:

Fig. 1 is a horizontal section taken through a preferred detector assembly with the associated amplifying and recording apparatus shown diagrammatically.

Fig. 2 is a front elevation of the detector assembly of Fig. 1, the detectors therein being shown in broken lines.

Fig. 3 represents a portion of a surface being surveyed with a detector shown moving thereover.

Fig. 4 is a portion of a record made by the detector assembly of Fig. 3.

Fig. 5 corresponds to Fig. 3 except that a different detector assembly is shown.

Fig. 6 is a portion of a record made by the detector assembly of Fig. 5.

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Fig. 7 is a diagrammatic showing of a modified detector assembly.

Fig. 8 is a perspective of another modified form of detector assembly with the amplifiers shown diagrammatically.

Figs. 9 and 10 are diagrammatic representations of modified detector arrangements, and

Fig. 11 represents an embodiment of the present invention in which the collimating shielding means are of a type which imposes a minimum of dead weight burden on the aircraft.

In one broad aspect, the invention contemplates prospecting of the surface of the earth by measuring substantially independently the radiation emanating from a number of limited-size areas of that surface and received at a corresponding number of respective points which have constant spaced-relationships to one another but are all moving relative to the surface of the earth, and correlating the measurements so obtained to determined anomalies in the prospecting area. More specifically, the invention involves the substantially independent measuring of radiation, such as gamma radiation received at a number of respective points in fixed spaced-relationship to one another and moving with respect to the prospected area, the radiation measured at each point being taken insofar as possible from a relatively small portion of the prospected area.

The term "substantially independent" as used herein is to be distinguished from any sense of absolute independency. This may be explained by restating the well-known fact that such detectors may be affected by radiation from all surrounding points, such as by cosmic radiation, air contamination, etc. In the present case therefore it is contemplated as preferable that the detector assembly as a whole be shielded as by suitable metal shielding insofar as possible from the undesirable radiation coming from points other than the area being explored; and that each individual detector, where a plurality of detectors is used in one assembly, be individually shielded so that a source of radiation which floods one of them will be unable to flood any other; and preferably also so as to exclude cosmic radiation and other undesired radiation insofar as possible so that there remains only a so-called open or sensitive face through which a principal axis of the individual lobe of sensitivity of that detector can be said to pass and to intersect the particular area under its observation. By using shielding between the detectors, the radiation which has entered one can be prevented from reaching any other whereby the individual detectors can be said to be substantially independent of one another.

The invention can best be explained by example. Assume that a relatively large section of the earth's surface is to be prospected. In the methods proposed heretofore involving radiation detection, detector assemblies characterized by their exposure to all of the radiation coming from relatively large areas at any given instant have been employed. In each unit of time which elapses while such a detector assembly is moved over the earth's surface, the assembly receives radiation from a total area which includes what may be termed a "steady area," this being a large intermediate area which is constantly within the zone of sensitivity of the detector during all of the interval; an increment of area which progressively comes within the zone of sensitivity, i. e., is "gained," in the direction of movement of the assembly during the interval; and an increment of area which is "lost" in the opposite direction during the interval, both of said increments being very small portions of said total area. In recording the radiation detected in one interval of time from such a total area, the assembly cannot perceive the presence therein of an increment which is significantly more or less radioactive than what is normal for the area. This is because the detector will integrate the radiation from the steady area, the increment being

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gained, and the increment being lost. Thus if one increment is low in intensity it may balance another increment which is high in intensity with the result that the total observed intensity may be the same as that of adjacent areas wherein all increments are of equal intensity. Thus an area containing an anomaly, either positive or negative, may be overlooked. In other words, not only does the detector integrate all of the radiation emanating from the large area to which it is exposed at any instant but in addition it integrates the radiation from the even larger area to which it is exposed during a finite interval of time while it is in motion.

From the above, it might be concluded that any attempt to observe more closely the radiation from ground areas should be accompanied necessarily by a corresponding decrease in the rate of progress of such a survey. Contrary to this supposition, the present invention provides a method wherein the rate of progress of such a survey can be maintained while insuring the resolution of substantially all anomalies of possible interest.

In a preferred embodiment of the invention, this is accomplished by employing a detector assembly including a plurality of detectors, each detector being substantially independent of the others, and all being arranged in a definite fixed relationship to one another. Such an assembly is shown in Figs. 1 and 2 wherein four detectors 11, 12, 13 and 14 are shown mounted in one assembly, the assembly being mounted in an aircraft with the exposed ends of the detectors facing downwardly as shown in Fig. 2. The assembly is shielded from side and top radiation including cosmic radiation by a shield 15 extending around the detector bundle and a cap 16 extending across the top thereof. Vertical partitions 17 and 18 function to shield the detectors so that the same radiation which enters any one of them will be unable to reach any other. The net result is a detector assembly composed of substantially independent detectors, the principal axes of sensitivity of the detectors being substantially parallel and extended downwardly as viewed in Fig. 2. By varying the length of the open-ended cylinder formed by shield 15, the ground area subject to observation by each detector can be varied correspondingly. For example, if shield 15 as viewed in Fig. 2 be increased in length, the extent of the ground area subject to each detector will be reduced. If the length of shield 15 be progressively reduced, without reducing the lengths of the vertical partitions 17, 18, the axes of sensitivity of the detectors will become progressively more divergent and the extent of the ground area under observation by each of them will be progressively increased. Ease and flexibility of adjustment of the effective length of the shield may be afforded in a variety of ways such as by providing a longitudinally slidable sleeve 15a about shield 15 and by mounting the partitions so that they are vertically slidable in the sleeve 15.

Each detector is provided preferably with its own preamplifier in conventional manner and connected to its own amplifier as shown at 11a, 12a, 13a, and 14a, each amplifier in turn being connected to recording apparatus of well-known type such as that employing an electronic voltmeter wherein the intensity variations detected by each detector can be recorded individually as by recorders 11b, 12b, 13b and 14b on a suitable record, the tracings being subsequently correlated.

Figs. 3 and 4 illustrate a typical survey, Fig. 3 being a plan view of a portion of the earth's surface. The prospecting is carried out by moving the detector assembly D, as in a helicopter, along predetermined lines of survey such as lines 19 and 20. An ore body having a typical horizontal outcrop A is shown. In proceeding along lines of survey 19 and 20 and using a detector assembly of the type wherein radiation from a large area is totaled, it is entirely possible that the anomaly incident to the ore body may be overlooked. The survey on line 20 would miss the anomaly entirely. In the survey

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on line 19, the radiation from the surface surrounding outcrop A might be of such low intensity as to balance any increase in intensity from the outcrop. Or if the ore body be of a non-radioactive mineral, i. e., a negative anomaly, the converse might be true.

In surveying the same area by the method of the present invention, detector assembly D carrying a plurality of substantially independent detectors 1, 2, 3 and 4 will be moved along the same survey line 19 in the direction indicated. By reason of the relatively small area of the surveyed surface from which radiation is passing to each detector, as contrasted to the size of the area supplying radiation to the previously discussed detector assembly, significant variations in the intensity of radiation are recorded as the detector assembly passes over outcrop A and the anomaly is betrayed.

This may be accomplished by recording the readings of detectors 1, 2, 3 and 4 separately as shown in Fig. 4. The pip on the trace of detector 1 shows clearly the change in intensity caused by the anomaly and also indicates the probable extent of the anomaly by reason of the degree of the pip size. This is corroborated by the trace of detector 3. The trace of detector 2 with its pip denotes a variation of less intensity and shorter duration, this being verified by the trace of detector 4. Thus independent traces are provided by each area and it is possible to determine not only the existence of the anomaly but also its probable outline. This can be done by spacing the base lines (quiescent or zero-input base lines) of the traces of the laterally adjacent detectors by an amount proportional to the spacing between the principal axes of sensitivity of the detectors and accordingly proportional to the spacing between the centers of the respective terrain strips from which those detectors receive radiation. Thus traces 1 and 2 will be proportionally spaced from one another as will traces 3 and 4. If lines T1 and T2 be drawn through the corresponding base ends of the pips as shown in Fig. 4, the result is a figure generally corresponding in outline to that of the anomaly. While the two detectors, 1 and 2, in adjacent relation may be sufficient to determine the anomaly, it is desirable to check or verify as by additional detectors 3 and 4.

It will be noted that all the above is accomplished by restricting the area from which the individual detectors receive radiation so that any appreciable increase or decrease in radiation intensity of any increments of appreciable size will be effective on the total radiation reported by the detector. Stated otherwise the area from which each detector receives radiation is kept relatively small to substantially eliminate any possibility of its having incremental parts which can balance out one another with opposite variations from normalcy in the intensities of their emitted radiations.

Once the existence, locations and general outline of an anomaly is determined, geologists may determine the significance thereof and the area can be further prospected as by boring and to more exactly determine its value. Where the radioactivity anomaly corresponds to an outcropping of an ore body, particularly if the ore contains a strongly radioactive material such as uranium, such further prospecting would obviously lead to the discovery of the main ore body.

Fig. 5 illustrates a different detector arrangement D' wherein the individual detectors are arranged on an axis generally transverse of the line of survey. In moving on line of survey 19 in the direction indicated, the detector assembly moves across outcrop A, the intensity variations measured by each detector being recorded as traces on the segment of the chart shown in Fig. 6. It will be noted that the pip in trace 1 indicates the edge of the main ore body as well as the base of outcrop A, the width of the base of the pip generally corresponding to the width of the base of the outcrop. The traces of detectors

2, 3 and 4 indicate variations of less extent and less duration.

It will be noted from Fig. 6 that by drawing lines T3 and T4 connecting the corresponding ends of the bases of the intensity variations as manifested by the pips, a rough outline of the outcrop can be made. As already stated this is best accomplished by spacing the traces apart in amounts approximately proportional to the spacing between centers of the terrain strips being surveyed. Knowing the position of the detector assembly with reference to the ground surface at the time of the variations, the location and extent of the anomaly can be quickly determined.

If desired, the individual detectors may be staggered as shown in Fig. 7 and shielded as by a housing 21 in the same manner as shown in Fig. 2 in which case there is some overlapping of the terrain strips under observation by the several detectors.

It is to be understood that where time permits, radioactivity prospecting as described herein, i. e., prospecting which uses a plurality of collimated detectors, may also be conducted on the surface of the earth or even underground in mining shafts as by an individual carrying the equipment pack-style or by mounting the equipment on a motor vehicle, the detectors being set up preferably in a manner to scan strips of the terrain on opposite sides of the vehicle as it moves along a line of survey. Where such surveys are to be conducted above the ground, as by helicopter, altitudes between 100 and 200 ft., preferably about 150 ft., are satisfactory. However operations may be readily conducted at higher altitudes and significant readings obtained because of the ability by collimating one or all of the detectors to confine their exposures to relatively small areas of earth surface despite increases in altitude. This becomes increasingly important as more sensitive detectors are used.

Preliminary reconnaissance surveys can be accomplished by the method disclosed herein by using detectors, such as an assembly thereof which are exposed to radiation from relatively large areas on the earth's surface, i. e., detectors which are not extremely directive. In such a case, the ground can be surveyed preliminarily with such detectors and thereafter the more interesting areas may be more carefully prospected by more stringent application of the method of this invention.

While the conventional Geiger-Mueller counter may be used in some cases, it is preferred to use other and more sensitive types of detectors especially where natural gamma radiation is to be determined. Faint differences in natural gamma ray intensities have frequently been usefully indicative of deeply buried ore deposits as well as of the lines of demarkation of contacts, faults and other geologic features. Accordingly it is preferred to use detectors having higher efficiencies for gamma rays than the conventional Geiger-Mueller detector. Ionization chambers are not generally satisfactory but scintillometers employing a fluorescent element of naphthalene or other phosphor to obtain scintillations which are measured by a photo multiplier tube, and detectors of the multiple-cathode plate type as disclosed in U. S. Patent No. 2,397,071 issued March 19, 1946, are quite satisfactory.

While mention has been made herein of a number of substantially independent detectors, it is to be understood that some types of multiple-anode detectors, ordinarily considered single detectors, may be used providing they be appropriately modified to function as a plurality of substantially independent detectors. Referring to Fig. 8, the detector shown therein diagrammatically is formed of a plurality of spaced cathode plates 22, the several plates being formed with a series of aligned holes 23 through which fine wires 24 forming anodes are passed. The detector is divided into a plurality of separate sectors or chambers as by one or more shields 25 and 26, arranged in the drawing to form quadrants as respects the cathode plates.

In this physical arrangement and with separate electrical output circuits for the respective anodes, the four detectors thus formed can be said to be substantially independent of one another, the manner of their performance being entirely comparable to the detector arrangement shown in Fig. 1. The four anode wires are respectively connected to suitable preamplifiers and separate amplifiers 27, 28, 29 and 30 and recording apparatus of the type shown in Fig. 2 so that the several traces can be individually recorded in the same manner as shown in Fig. 1, the operation of the device being the same as described in connection with Figs. 3 and 4. It is to be understood that the cathode plates can be arranged in other ways such as those shown in the above identified patent and that a single partitioning element 25 or a different plurality thereof may be used to vary the number of substantially independent detectors. The apparatus shown in Fig. 8 is also shown and described in co-pending application, Pat. No. 2,699,513 which was filed on March 18, 1950, the said apparatus being claimed in that application and not herein.

In some instances, it may be desirable to vary the distance between ground areas under observation by the individual detectors. This may be done by mounting the detectors as shown in Fig. 9 wherein two detectors 41 and 42 are shown to be angularly movable about a pivot 43, which is suitably mounted on a support such as a helicopter. By adjusting the detectors in a manner to change the angle between them, for example as shown on a quadrant, the distance between the ground areas on the surface under observation by each detector can be adjusted proportionally.

In the arrangement shown in Fig. 10, detectors 44 and 45 are mounted on lateral supports 46 and 47 on a helicopter. Each detector is mounted on a rack or equivalent means so that it can be adjusted along its support to and from the body of the helicopter. Thus by moving the detectors to the positions shown in dotted lines, the ground areas under observation are brought closer together. By moving the detectors outwardly, the ground areas are moved further apart.

The embodiment shown in Fig. 11 is arranged to maintain constant the downward directivity of a detector's lobe of sensitivity. In addition it utilizes a type of collimating shield which imposes a minimum of dead weight burden upon the aircraft without any substantial sacrifice in the effectiveness with which it accomplishes its intended function. The detector represented at 50 in Fig. 11 by way of example is a single detector of similar cylindrical shape to Geiger-Mueller detectors and to certain multiple plate detectors. However, if preferred it may have any one of a number of different shapes, e. g., it may be cube or slab shaped or it may have the same cylindrical shape as shown herein but be mounted with its axis in a horizontal position rather than standing on end, and instead of being a single detector it may consist of a plurality thereof compactly arranged in a bundle and electrically connected in parallel. Moreover, as pointed out above, it may be a scintillometer and as such be of any suitable geometry and positioned in any suitable way. For any particular geometrical shape of the detector 50 a shield which is intended to collimate upward radiation so that the detector will "see" only a predetermined small ground area must have a radiation-impermeable portion which lies between the radiation sensitive bottom surface of the detector and ground areas which surround said small area and whose emanations of radiation it is wished to exclude from the detector. In the Fig. 2 embodiment the portion of the shielding arrangement 15, 15a, 17 and 18 which does this is the lower portion thereof which extends downward below the lower periphery of the detectors 11-14. As will be explained below, its upper portion, i. e., the upper half of the shield 15 and the cap 16, actually are not necessary for collimating the ground emanations, though, to be sure they are very useful for excluding side and top

radiation such as radiation coming from air radioactivity and from outer spaces respectively. Not only must the portion which has the collimating effect with respect to ground emanations lie between the bottom of the detector and the ground but in addition it must be more and more distant from the bottom of the detector as the aircraft mounts to higher and higher altitudes and as the exposed bottom area of the detector is greater and greater in size. Thus the type of collimating shield which is shown in Fig. 2 may sometimes have to be of considerable length, and therefore present a very undesirable dead weight burden, if a high degree of resolving power is to be maintained even though (1) a survey is to be conducted at the fairly high altitudes, and (2) a large area detector is to be used (to make up for the fact that the flux density of natural gamma radiation will be very low at such altitudes).

However, this is not true of the type of shielding arrangement shown in Fig. 11. This arrangement makes use of the fact that radiation which leaves the earth in the direction of the detector but from points at substantial distances from the point on the ground directly beneath the detector will have such long slant paths of travel to reach the detector that they will often be absorbed without the use of shielding. Since this is so, very effective collimation can be attained by blocking-off only those slant paths which extend to the detector from a limited region, e. g., the annular region 51 shown in Fig. 11, surrounding the small ground area, 52, under surveillance directly below the detector.

The outer periphery of the region 51 may be determined in practice as the boundary beyond which gamma rays directed toward the aircraft have such long slant ranges that no more than a negligible percentage of them will be able to reach it. Accordingly all that is necessary is that the collimating shield intercept all radiation paths from the ground to the detector which lies outside of the imaginary cone 53 representing the intended lobe of sensitivity for the detector and inside of the cone defined by imaginary lines, 54, extending between the outer periphery of the region 51 and the detector 50. Accordingly such a shield may simply take the form of a flat plate, say of lead, which is circular in shape and has a round hole at its center. Moreover if, like the plate 55 in Fig. 11, it has the shape of a section of a sphere whose center coincides with that of the detector 50 it will have even less dead weight, this being also true to an approximation if it has the shape of an apertured inverted frustum so shallow as to be tangential to the lower surface of the shield 55. Inasmuch as the slant ranges of gamma rays become progressively longer as they emanate from parts of the region 51 progressively nearer to its outer periphery, and since therefore the amounts of air-absorption and distance-attenuation (in accordance with the inverse square law) will also increase progressively, the shield 55 may be made thinner near to its outer periphery than near its center opening without any substantial sacrifice in its effectiveness.

The detector 50 is mounted in a gimbal arrangement 56 having reverse axes 56a and 56b. Thus the detector 50, the rods 57 and the shield 55 constitute an assembly articulately coupled to the aircraft at a point on the assembly which is well above its center of mass with the shield 55 suspended below it so that its weight can serve to maintain downward orientation of the directivity of the detector. To prevent the air stream from tilting back the detector away from the direction of flight it may be covered with a windshield in the form of a radiation-permeable canopy 58, the whole being suitably mounted on a vehicle such as a helicopter. While they are not shown in this figure it is intended to be understood that the usual output circuit components will be employed in conjunction with and suitably connected to the detector 50.

Obviously, if desired, a more complicated arrangement including one or more gyroscopes and a servo system

might be employed for maintaining downward orientation in lieu of the simple gravity-actuated arrangement of Fig. 11.

Where it is desired to reduce the "background" counts to a minimum, top and side shielding of the body of the detector may be used in conjunction with a disc-type shield, like the shield 55 and in many installations the total weight of the shielding will still be less than that of a corresponding shield of the kind shown in Fig. 2.

Where it is possible to control the flight stability to such an extent that there is no necessity of using means for maintaining downward directivity for the detector a simple structural arrangement which may prove to be suitable will be that of mounting the detector near a top portion of the air frame of the craft such as near the ceiling of the fuselage or the top surface of the wing while an apertured collimating plate is fastened to a part of the air frame directly below such as to the floor of the fuselage or the bottom surface of the wing. In such an arrangement, or in the arrangement of Fig. 11 with its lightweight tie rods 57, heavy material is used only where it serves a definite shielding function.

While only one collimated detector or detector means is shown in Fig. 11, it is intended that according to the present invention a number of such detectors or detector means may be used for example in the manner shown in Fig. 10. Moreover, if it be desired to mount such detectors more closely side by side, as in Fig. 9, the Fig. 11 arrangement for controlling the directivity of the detector may be adjusted so as to tilt the detectors' lobes of sensitivity slightly away from one another and to thereafter maintain them in that orientation. To this end a slotted weight 59 is provided which may be slipped over the protruding bottom end of any one of the tie rods 57; fastened thereto; and adjusted thereon to automatically control the exact downward direction of the associated detector's lobe of sensitivity.

The degree of collimation afforded by the arrangement shown in Fig. 11 can be adjusted by moving the plate 55 upwards or downwards on the tie rods 57 and fixing it at any position so selected by tightening set screws in retaining means such as the collars shown at 60. Where relatively large adjustments are contemplated a number of different plates 55 of different sizes may be made available and the rods 57 may have their upper ends articulately connected to the detector 50.

Tests of the present invention have shown it possible to locate radioactivity anomalies with collimating shielding which could not be located without it.

Obviously many modifications and variations of the invention, as hereinbefore set forth may be made without departing from the spirit and scope thereof, and therefore only such limitations should be imposed as are indicated in the appended claims.

I claim:

1. In geophysical operations involving the measurement of gamma rays emitted by the earth along a traverse of its surface, the improvement which comprises the steps of detecting radiation from selected areas of the earth surface by moving a plurality of detector units over and relative to said surface, said units being substantially shielded from one another and from radiation other than from the earth surface and arranged in closely adjacent and fixed relation to one another, said units being positioned in a line substantially normal to said line of traverse whereby the radiation measured by each unit at any instant is substantially from a different area of said surface, which areas lie along a line substantially normal to said line of traverse, and separately and continuously recording the measurements from said units while correlating said measurements with respect to the movement of said units relative to the earth surface.

2. The improvement of claim 1 wherein said detector units are moved in a plane substantially parallel to the earth surface whereby the area scanned by each detector

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unit is in the shape of a ribbon of substantially uniform width and substantially parallel to said line of traverse.

3. Geophysical apparatus for the measurement of gamma rays emitted by the earth along a traverse of its surface, the apparatus being mounted on an aircraft and comprising a plurality of detector units for detecting gamma radiation from selected areas of the earth surface, said detector units being substantially individually shielded from radiation other than from respective discrete areas of the earth surface and being arranged in fixed relation to one another, said units being positioned in a line substantially normal to said line of traverse, whereby the radiation measured by each unit at any instant is substantially from a different area of said surface which areas lie along a line substantially normal to said line of traverse, and means for separately and continuously recording and correlating the measurements from said units on a single tape, whereby the apparatus can provide plural and correlated indications of a common geophysical anomaly.

4. Geophysical apparatus for the measurement of gamma rays emitted by the earth along a traverse of its surface, the apparatus being mounted on an aircraft and comprising a plurality of detector units for detecting gamma radiation from selected areas of the earth surface, said detector units being substantially individually shielded from radiation other than from respective discrete areas of the earth surface and being arranged in fixed relation to one another, said units being positioned in a line substantially normal to said line of traverse, whereby the radiation measured by each unit at any instant is substantially from a different area of said surface which areas lie along a line substantially normal to said line of traverse, and means for separately and continuously recording and correlating the measurements from said units, whereby the apparatus can provide plural and correlated indications of a common geophysical anomaly.

5. Geophysical apparatus for the measurement of gamma rays emitted by the earth along a traverse of its surface, the apparatus being mounted on an aircraft and comprising a plurality of detector units for detecting gamma radiation from selected areas of the earth surface, said detector units being substantially individually shielded from radiation other than from respective discrete areas of the earth surface and being arranged in

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fixed relation to one another, at least two of said units being positioned on opposite sides of a line parallel to the line of traverse, whereby the radiation measured by said two units is from different areas which areas are displaced from one another in a direction substantially normal to the line of traverse, and means for separately and continuously recording and correlating the measurements from said units, whereby the apparatus can provide plural and correlated indications of a common geophysical anomaly.

6. In geophysical operations involving the measurement of gamma rays emitted by the earth along a traverse of its surface, the improvement which comprises the steps of detecting radiation from selected areas of the earth surface by moving a plurality of detector units over and relative to said surface, said units being substantially shielded from one another and from radiation other than from the earth surface and arranged in closely adjacent and fixed relation to one another, at least two of said units being positioned on opposite sides of a line parallel to the line of traverse, whereby the radiation measured by said two units is from different areas which areas are displaced from one another in a direction substantially normal to the line of traverse, and means for separately and continuously recording and correlating the measurements from said units, whereby the apparatus can provide plural and correlated indications of a common geophysical anomaly.

7. The apparatus of claim 4 which further comprises means for mounting said apparatus on an aircraft for universal movement relative to the aircraft in order to maintain the detector apparatus in vertical alignment during flight of said aircraft.

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