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PROSPECTING FOR URANIUM WITH CAR-MOUNTED EQUIPMENT

By
John M. Nelson

This preliminary report is released without editorial and technical review for conformity with official standards and nomenclature, to make the information available to interested organizations and to stimulate the search for uranium deposits.

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By John M. Nelson

ABSTRACT

The U. S. Geological Survey on behalf of the Atomic Energy Commission has prospected for uranium with a car-mounted Geiger-Mueller counter for the past several field seasons. The basic principles of the car-traverse technique are simple. Rocks and soils of abnormally high uranium or thorium content are surrounded by an abnormally high gamma radiation field. Where an abnormal gamma radiation field extends across a road or highway, it can be detected by a suitable Geiger-Mueller counter mounted on a car or truck travelling at relatively high speeds. Once detected by car-traversing, the deposit can be examined on foot with light-weight portable instruments, and the more promising parts can be sampled. The prime advantage of the technique is the rapid rate of the scanning process, 100 to 200 miles per day, which permits exploration of large areas in a short time.

INTRODUCTION

Commercial production of rugged portable radioactivity detectors opened the way for prospecting on foot without exhaustive sampling. Recent improvements in equipment permit detection of radioactive deposits from a moving car, train, or boat. The objective in all cases is to use the fastest and most productive method of detecting radioactive deposits in a given area.

Experiments by the U. S. Geological Survey with car-mounted Geiger-Mueller counters started in 1945 and have continued through 1949. Standard equipment, modified for the car-traverse technique, has been used wherever possible. In this paper, the results of the experiments are presented, the instruments described, and operational procedures are suggested.

This paper is based on the work of many geologists on the Geological Survey staff. The 1948 field tests of the car-traverse technique had the special interest of Thomas A. Hendricks, then Chief of the Trace Elements Planning and Coordination Office of the Survey. Harold Arndt, Russell Flowers, Donald H. Johnson, Frank A. McKeown, Perry Narten, and Edward Stratton actively used the car-traverse technique in the field.

DISTRIBUTION OF RADIOACTIVITY IN THE EARTH'S CRUST

The distribution of radioactivity based on measurements taken at 2,200 outcrops of sedimentary, metamorphic, and igneous rocks in an area of 30,000 square miles is illustrated in figure 1. The radioactivities of nearly all outcrops in this area are in the range between 0.0002 and 0.004 percent equivalent uranium. Radioactivities in this range are called normal and do not aid the prospector searching for a uranium deposit. Few rocks in the area have a radioactivity of 0.005 percent equivalent uranium or more. Radioactivities in this higher range are called abnormal and indicate an abnormally high

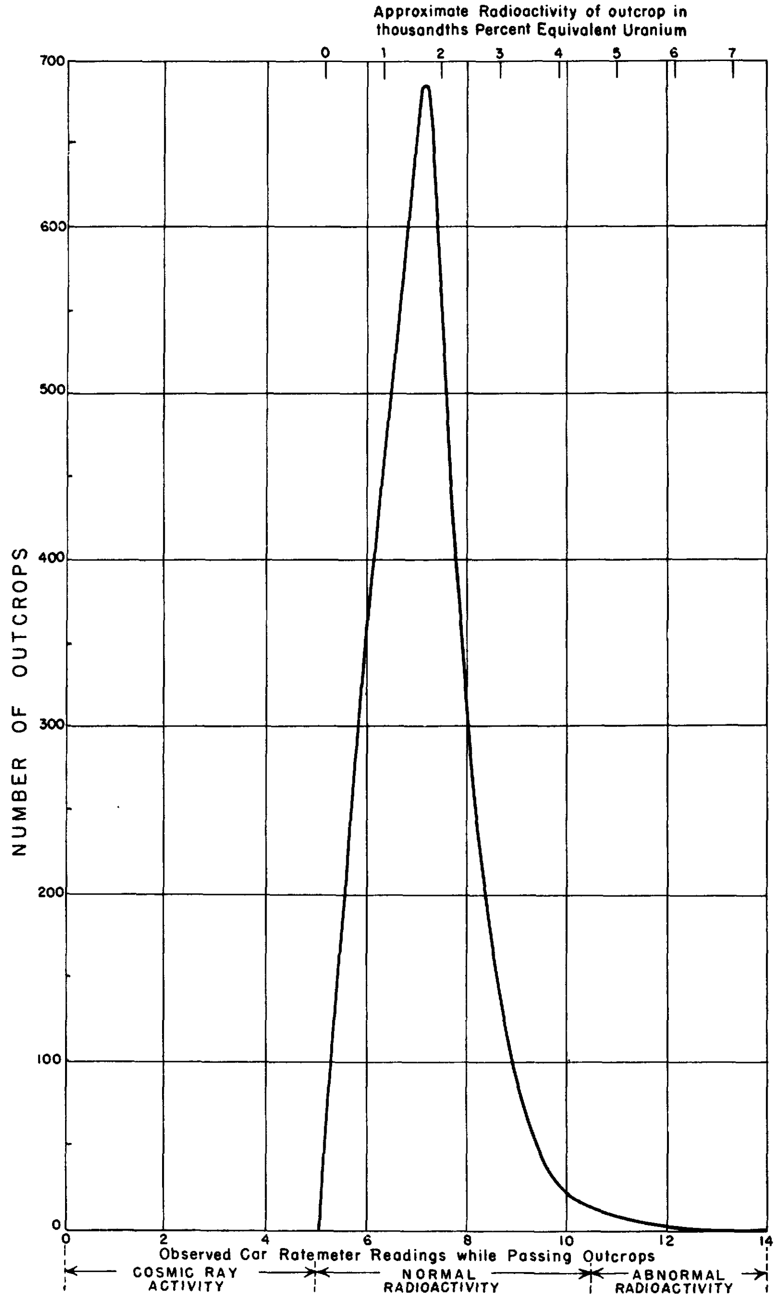


Fig. 1.- CURVE SHOWING DISTRIBUTION OF OUTCROP RADIOACTIVITIES

concentration of uranium or thorium in the rock. The objective of prospecting with gamma-ray equipment is the detection of the abnormal gamma radiation field surrounding rocks of abnormal radioactivity.

RESPONSE OF GAMMA-RAY EQUIPMENT TO COSMIC RAYS AND RADIOACTIVE ROCKS

Gamma-ray equipment responds to both cosmic rays originating in outer space and to gamma rays originating in substances in the vicinity of the instrument. The response to cosmic rays for an instrument, at a given elevation above sea level, and at a given latitude may be determined by noting the instrument response over essentially non-radioactive water of a depth of 10 feet or more, at a considerable distance from shore. This may be done from a steel or wooden boat or bridge. The response to cosmic rays may be determined with less accuracy by noting the lowest consistent response while carrying the instrument across a thick section of sandstone, limestone, or basalt, which are generally of very low radioactivity. These measurements of cosmic ray activity (the basic response) include the minor radioactivity originating in the air and the instrument.

Responses in excess of the basic response are caused by radioactive rocks, soils, or other substances in the vicinity of the instrument and directly reflect the degree of radioactivity in the vicinity of the instrument. The degree of instrument response in excess of basic response is the quantity to be measured by the prospector.

The response of gamma-ray equipment to a given source of radioactive material is a function of (1) the solid angle between the source material and the detector and (2) the absorption of gamma rays by the intervening air. The solid angle is subtended, from the instrument at the apex, by the boundaries of the surface of the source material.

The instrument response varies directly with the size of the solid angle between the instrument and the radioactive source material. The response is greatest in underground workings or in a highway tunnel, where the solid angle between instrument and radioactive source material is the largest possible. The response is only one-half as great for the same source material on a level plain where the solid angle is half as large. The instrument response is extremely small for source material of the same radioactivity where the instrument is many feet from a few square inches of the exposed radioactive outcrop and the solid angle is extremely small. The solid angle and instrument response decrease with the square of the distance.

In addition to the affect of solid angle, the amount of intervening air affects the instrument response, because it absorbs gamma radiation. At a distance of about 300 feet, approximately one-half of the gamma rays emitted by the uranium series is absorbed, and the instrument response is reduced proportionally. For practical purposes, the limit of detection of extremely large high-grade deposits is about 1,000 feet.

Where the gamma radiation field of a uranium deposit extends across a road or highway, it can be detected by equipment mounted on a moving car or truck. The gamma radiation field of a deposit discovered while car-traversing at a speed of 30 miles per hour is shown in figures 2A and 2B.

CAR-MOUNTED EQUIPMENT

Development of present equipment

The car-traverse technique was first used by A. L. Slaughter and John M. Nelson in 1945. The instrument used in the car was extremely simple, consisting of a Geiger-Mueller counter with a response of 12 pulses per minute in an environment of average activity, a small amplifier, and a pair of earphones. At normal driving speeds, this instrument detected several radioactive roadside deposits, although the pulse rate was much too low for the desired accuracy.

In 1946 and 1947, a larger Geiger-Mueller tube, having a response of 500 pulses per minute, feeding into a counting-rate meter, was used. With this instrument, several new radioactive deposits were detected. The pulse rate was still too low for the desired accuracy, and the time constant of the counting-rate meter circuit, one minute, was too long for fast traversing.

In 1948, somewhat better equipment was obtained. Two Geiger-Mueller tubes, each having a response of 1500 pulses per minute, were connected to a counting-rate meter circuit having a time constant of about 15 seconds.

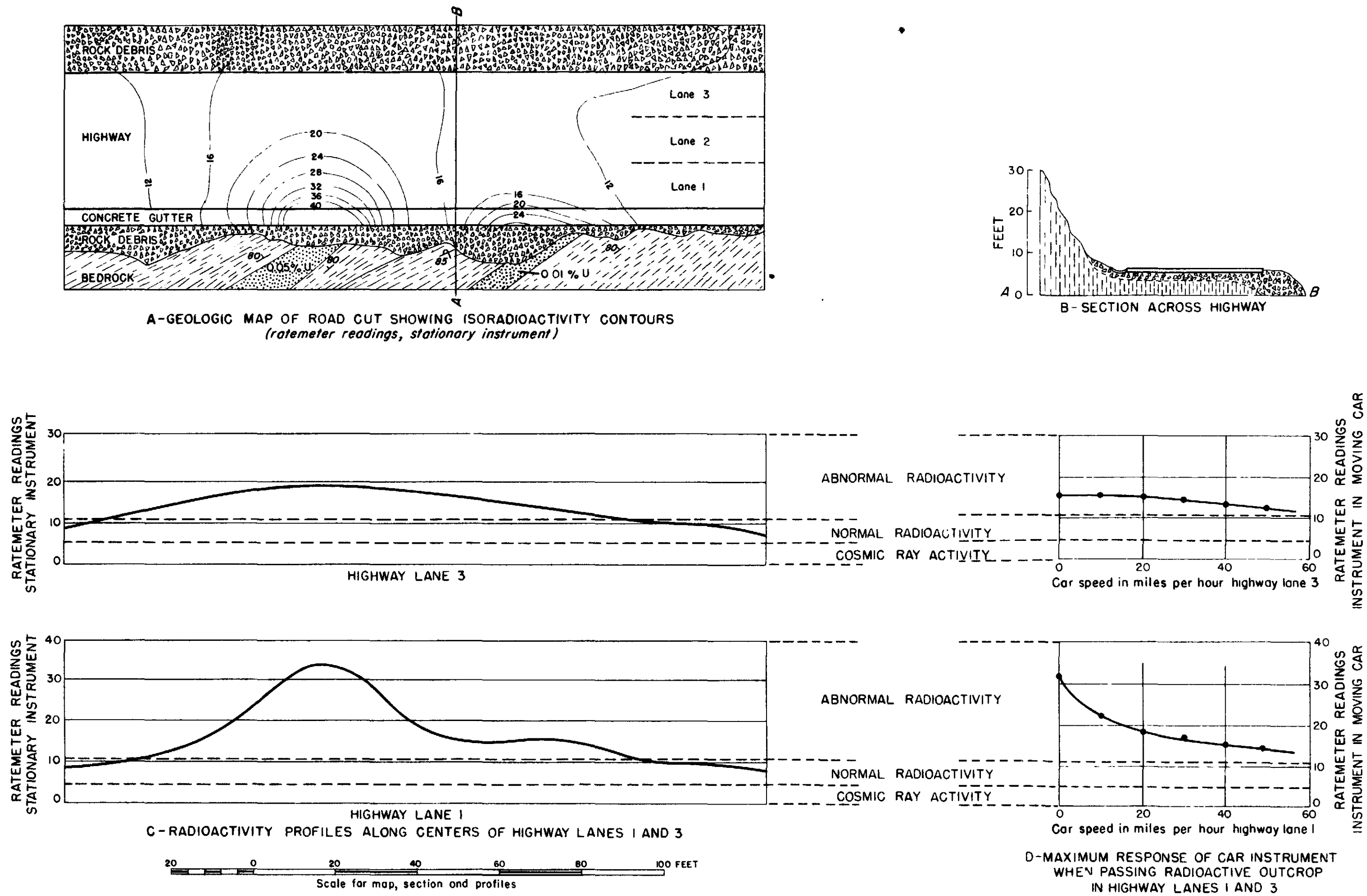


Figure 2 — Gamma field of radioactive outcrop and response of car-mounted Geiger - Mueller counter

One Geiger-Mueller tube was attached to each side of a panel delivery truck (fig. 3). The counting-rate assembly was placed in a convenient position between the two seats, and an alarm circuit was located behind the driver's seat (fig. 3). The general layout of the units is shown in figure 4.

The alarm circuit (fig. 5), designed and constructed by Donald H. Johnson of the Geological Survey, is connected across the counting-rate microammeter. The voltage across the microammeter varies directly with the response of the instrument to a radioactive field. The alarm circuit amplifies the voltage difference, and, by varying the bias on either vacuum tube, the alarm can be adjusted to ring at any desired reading of the counting-rate meter. The automatic alarm circuit permits the geologist observer to keep his eyes on the roadside rocks.

Three sedan panel delivery trucks were outfitted with this equipment and were operated in the late summer and fall of 1948. The usefulness and limitations of this instrument are graphically shown in figures 2C and 2D.

Figure 2C shows the gamma radiation field through which the truck traveled on two highway lanes; figure 2D shows the response of the instrument to the radioactive field at several car speeds. While passing the radioactive deposits at speeds of less than 10 miles per hour, the maximum response of the car-mounted instrument closely approaches the value of the gamma radiation field through which it passes. At progressively higher speeds, the instrument response decreases. Altnough the response of this instrument is sufficient to trigger the alarm circuit at speeds up to 50 miles

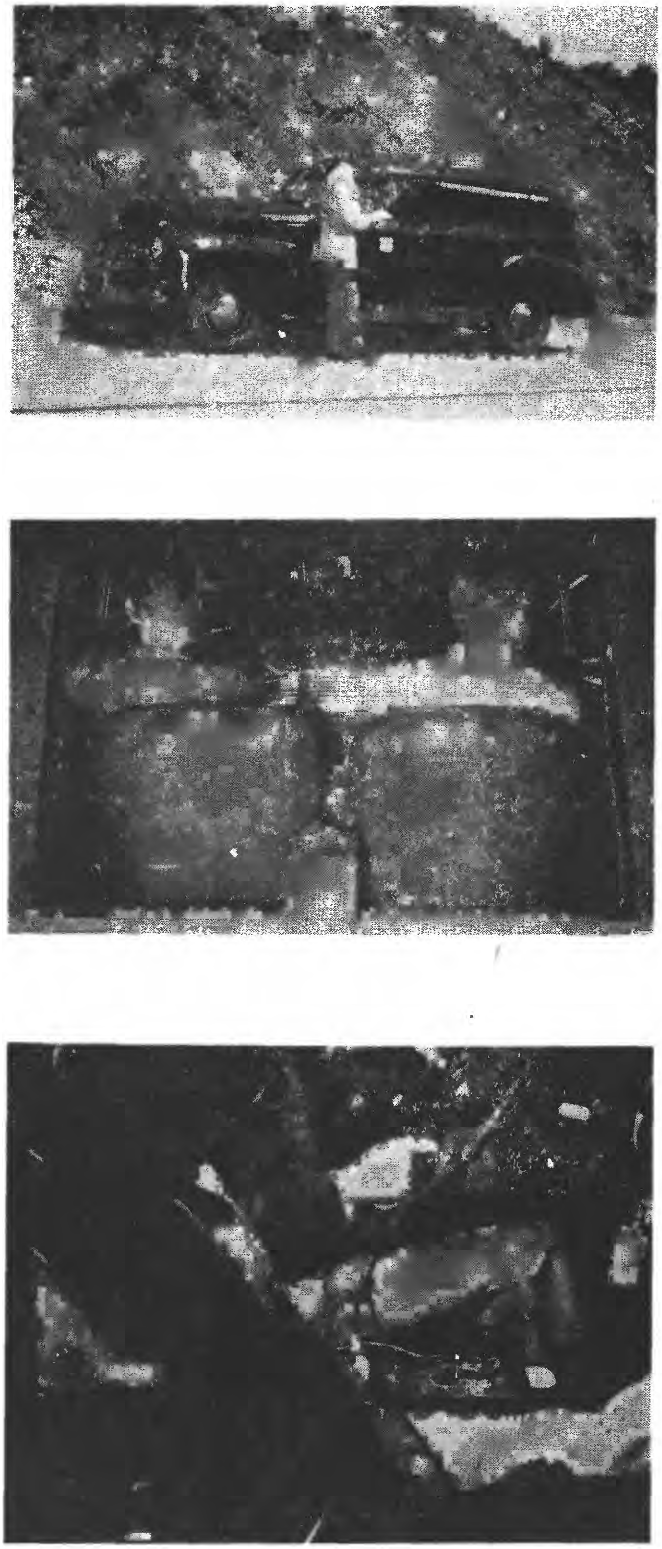
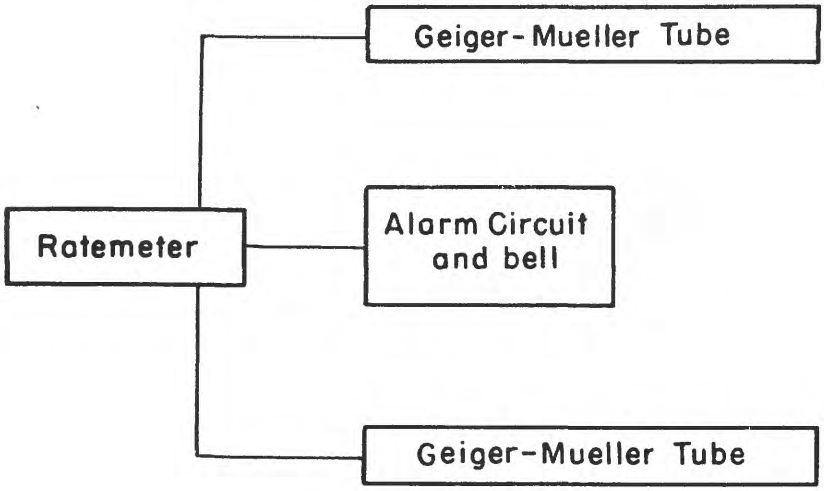


Fig. 3 Prospecting equipment showing Geiger-Mueller tubes on side of car, alarm behind seats, and ratemeter between seats.



EXPLANATION

Geiger-Mueller tubes are brass cathodes, 2 inches in diameter and 42 inches long, mounted on the exterior of car as high as possible.

Ratemeter modified for use with the large Geiger-Mueller tubes by addition of batteries to produce 1120 volts. The instrument is mounted inside the car where the microammeter can be easily read by the operator.

Alarm circuit and bell are mounted inside the car conveniently close to the operator.

Fig. 4. Diagram of components of car-mounted instruments

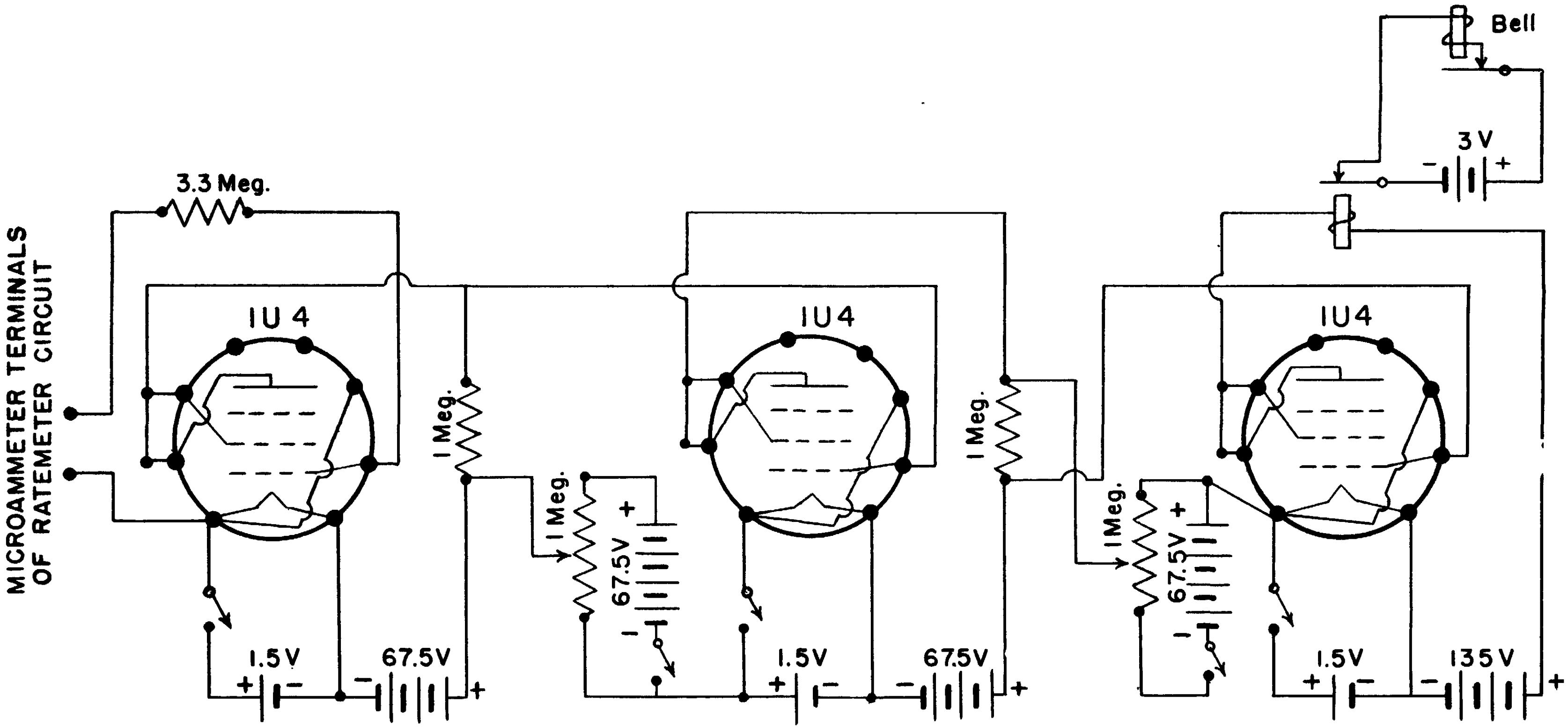


Fig. 5 — SCHEMATIC DIAGRAM OF ALARM CIRCUIT

per hour in highway lane 3 and at an estimated speed of up to 80 miles per hour in highway lane 1, smaller deposits located farther from the road might remain undetected by the instrument.

Desired performance of future equipment

The performance requirements of future equipment are based on three factors: (1) desired reproducibility of measurements, (2) length of traverse per individual measurement, and (3) speed of vehicle travel.

The desired reproducibility of measurement is a standard deviation of plus or minus 10 percent. As the standard deviation in percent roughly equals $\frac{\sqrt{N}}{N} \times 100$, where N is the total number of pulses in the measurement, a standard deviation of 10 percent requires a minimum of 100 pulses per measurement. From figure 1, it may be seen that this degree of reproducibility is adequate to detect significant abnormalities.

The length of traverse during which the radioactivity of the environment is measured is based on the minimum width of an abnormal gamma radiation field through which the equipment might pass. A consecutive series of individual measurements, each giving the average radioactivity of a ten-foot traverse interval, is considered adequate for the detection of the deposit shown in figure 2A and for smaller deposits.

The maximum speed of vehicle travel is limited by human factors. Field experience shows that the geologist observer can roughly identify the roadside rocks up to speeds of 30 miles per hour, if he stops to check his identification when in doubt.

These considerations indicate that the desired equipment should be capable of a pulse rate of 100 pulses per 10-foot interval. At a speed of 30 miles per hour, the ten-foot intervals are traversed in approximately one-fifth second and the required pulse rate for areas of normal radioactivity is 100 pulses per one-fifth second or 30,000 pulses per minute.

Suggested methods of obtaining the desired performance

Although the instruments described in this paper have proved their value in prospecting for radioactive source materials, they are essentially simple and crude. Many necessary improvements can be made at this time.

First, the desired pulse rate of 30,000 pulses per minute can be obtained by in-parallel coupling of 20 brass-walled Geiger-Mueller tubes, 42 inches in length and 2 inches in diameter. These tubes are produced commercially and are available.

Second, the desired speed of response, sufficient to give a continuous series of radioactivity measurements, can be obtained either by decreasing the time constant of a counting-rate meter circuit or by using a scaler circuit, at a scale of 100. In the latter case, each hundredth pulse could be recorded on moving tape by means of electric sparks or other means, and the distance between spark holes on the tape would vary inversely with the radioactivity. Other methods of obtaining fast instrumental response will be obvious to personnel trained in electronics.

The position of the Geiger-Mueller tubes on the vehicle is important. The highest possible location of the tubes on or above the vehicle will permit the greatest instrumental response because of the larger solid angle between Geiger-Mueller tubes and roadside rocks. However, low bridges over roads limit the practical height of the tubes to between 7 and 10 feet above road level, depending on the region.

The response of the instrument to the roadside rocks is also dependent on the geometric arrangement of the gamma tubes. The objective is to arrange the tubes in a pattern so that they will be actuated to the fullest possible degree by gamma rays emitted from the roadside rocks, and to the least possible extent by gamma rays emitted from the underlying road materials and by cosmic rays descending from above. The simplest efficient arrangement is obtained by forming a single vertical bank of 20 contiguous tubes, symmetrically mounted above the vehicle, with the axes of the tubes horizontal and parallel to the travel path of the vehicle. The tubes in this position present the largest possible target for gamma rays emitted from the roadside rocks, and one of the smallest possible targets for gamma rays emitted by the road materials and for cosmic rays from above. This arrangement also decreases the percentage of coincidence counts from the roadside, and increases the percentage from above and below. Moreover, the vehicle partly shields the tubes from the gamma rays emitted from the road materials and reduces the number of these gamma rays that reach the tube.

Perferential response of the instrument to gamma rays emitted by roadside rocks over those emitted by the road material and cosmic rays may also be obtained by the use of coincidence and anti-coincidence circuits, with a variety of gamma tube arrangements. The decreased complexity of such circuits may or may not outweigh their advantages. Their relative merits cannot be evaluated until they are used in the field.

TYPES OF CAR-TRAVERSE PROGRAMS

The car-traverse technique has several applications. Its most important use is in fast reconnaissance of large untested areas. Other uses are: exploration in a wide area around known deposits, traversing to and from mining properties, and objective exploration of all rocks and soils in areas where the most favorable rocks have already been examined.

Car-traversing, with its high speed of 100 to 200 miles per day, makes it possible to investigate large areas of untested rocks in a short time. Its ability to detect the few abnormally radioactive rocks and soils in such an area gives a relatively complete radioactivity profile along the roads traversed.

The car-traverse technique may also be used to explore a wide area around a known radioactive deposit; its speed and low cost permit exploration extending beyond the limits of the more common exploration techniques. A field party using this technique in the general vicinity of a syngenetic deposit in conglomerate discovered a second syngenetic deposit in a sandstone of widely different age. The objective scanning of all roadside rocks in this case produced a discovery which would not have been made by a routine examination of this and adjacent formations.

The technique has been used successfully on routine trips to and from mining properties and other specific points of interest. The value of this use of the technique lies in the utilization of normal travel time, which would otherwise be wasted, to test roadside rocks and soils that would not routinely be investigated. A number of abnormally radioactive rocks were discovered in this manner in 1945, 1946, and 1947.

Even though the most favorable rocks in an area have already been examined, the objective exploration of less favorable rocks and soils may prove profitable. For example, while driving through an area of known radioactive minerals, one car-traverse party discovered an additional highly radioactive soil zone.

PREPARATION FOR THE FIELD

Regardless of the use to which the car-traverse technique is put, the following preparation is required if the field party is to take full advantage of the potential rapidity of the technique.

The area to be investigated must be selected and limited after consideration of its geology. The area should be subdivided into geologic divisions of varying promise, and the tentative time of exploration in each subdivision should be allotted accordingly. The geologic information of the area should be studied and indexed for field use. The field parties have found it most convenient to have all pertinent data plotted on index maps of the area. Known localities of radioactive rocks and localities of special geologic interest may be plotted on one index map; portions of the area covered by geologic maps may be plotted on a second index map; portions of the area described in publications may be plotted on a third index map. The speed with which the car-traverse technique can be employed is such that the field party may find that it has passed within a mile or two of a point of interest after it is several hundred miles beyond the point, unless all information is available in simplified form.

In addition to the car-mounted equipment, the party requires a portable gamma counting-rate meter of normal pulse rate, 1000 or more pulses per minute, for detailed scanning of localities found by the car-traverse technique; a portable scaler and a jaw-crusher are desirable for determining the radioactivity of samples. Equipment for determining the radioactivity of the samples to the nearest thousandth percent equivalent uranium, while at the radioactive locality, permits the field party to make an immediate decision on the length of time to be allotted to local examination. If the field party waits for quantitative results obtained from the laboratory, it may find itself hundreds of miles from the locality, and may have to return to it, or it may find that an unjustified amount of time has been spent at a locality of low grade rock.

The parties also require three standard samples (one low, one medium, and one high grade), which have the density of common rocks, and which are crushed to the same size as the samples collected in the field. The standard samples should consist of uranium in equilibrium with its daughter elements, thoroughly mixed with a diluent of average rock density. Pitchblende thoroughly mixed with non-radioactive portland cement, cast and crushed to the proper size, has proved satisfactory.

The personnel required depends on the type of equipment and the information desired. A two-man party is generally desirable, but if the equipment includes an adjustable alarm, or if the radioactivity is automatically recorded and a continuous record of the geology is not required, one man can do the job. The personnel should be trained in maintenance and repair of the electronic equipment.

Uninterrupted hours of complete concentration on the geology of the area being traversed, and its relation to the observed radioactivities of the rocks, causes extreme fatigue for the geologist. For this reason, it is desirable that the party consist of two geologists, so that one can relieve the other at frequent intervals. If the prospecting is on a large scale, the specially equipped car may be kept in the field the year round by the interchange of parties between the field and the office. If the prospecting is on a smaller scale and no replacements are available, the car-traverse party will probably have to do the detailed mapping of the radioactive localities, and in so doing will obtain relief from the strain of car-traversing.

RECORDING FIELD DATA

Recording of car-traverse data can be as simple or as complex as desired. In their simplest form the data consist of the roads traversed, recorded in pencil or ink directly on a road map, together with the exact location of any locality of sufficiently high radioactivity to interest the observer. A more complete recording of data would include, in addition to the foregoing, a complete radioactivity profile of the road traversed, together with the observed geology. This latter type of recording has the advantage of preserving smaller peaks of radioactivity, which, when integrated from one road to another, may indicate an intervening area of promise. However, this complex system of recording has the disadvantages of being hard on the observer and of accumulating tremendous amounts of data that require a lengthy office period for analysis.

SUMMARY

Active field work has shown many advantages of the car-traverse technique over spot examination of outcrops with the hand counter. The coverage of 100 to 200 miles of roadside rocks and soils per day permits examination of large untested areas, which could not be investigated in a reasonable length of time by slower methods. Its utility is not diminished by brush, rain, or light snow, and it can be continued after sunset. The continuous and objective scanning of all rocks and soils along the routes traveled has disclosed uranium in rocks previously believed to be essentially barren. This objective characteristic of the technique is of considerable importance, because the use of uranium as a source material for atomic energy has created a demand for low grade ores, whose associations and distribution are not completely known.

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