

USE OF RADIOISOTOPES IN HYDRAULIC STUDIES

by

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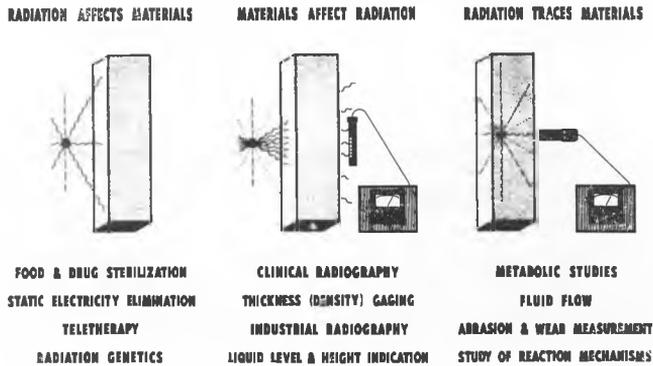
Radioactive tracers provide tools long needed by hydraulic engineers. Their powers are unaffected by changing chemical and physical conditions and they can be detected in very low concentrations, much lower than is possible with dye or salt. Radiotracers give a more accurate picture of actual flow-through curves of basins and conduits by bringing out the longer tails of the build-up and fall-off curves which go undetected by other means [1]. Also, density effects from radioisotopes are vanishingly small as only micro-amounts of the material are required. In most cases radiotracers may be followed by taking readings through the pipe or tank wall, thus leaving the flow pattern undisturbed. The following discussion alludes to hydraulics in its broadest sense, that is, the general behavior of all liquids. Although the examples cited deal with many different liquids, the basic principles can usually be applied to problems in water measurement.

PRINCIPLES OF USE

It would be difficult to conceive of a more sensitive or versatile tool than the radioactive atom. The most familiar use of radioisotopes is as sources of radiation. Here the type of emitted radiation, its energy and the half-life are the principal considerations, and generally the right combination of the three can be found to meet most needs.

The second principal use of radioisotopes is as tracer atoms. The radiation from radioisotopes gives investigators an extremely sensitive means of detecting their presence and hence their movement through physical or physical-chemical transfer, or in a chemical reaction. Here the chemical form of the radiomaterial as well as its radiation and half-life determine its usefulness. Since radioisotopes of most of the elements are available, a suitable tracer can be found for most purposes.

The fundamental principles involved may be reduced to three major types or modes of use as shown in Fig. 1.



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FIG. 1. BASIC PRINCIPLES OF RADIOISOTOPE UTILIZATION

Effect of Radiation on Materials

In the first type of use the radioisotope is used simply as a fixed source of radiation much as radium and X-ray machines are used. The ability of radiation to alter a material is indeed important in many ways. This type of use, however, does not lend itself to a testing procedure and will not be discussed further.

Effects of Materials on Radiation

In the second type of use (Fig. 1) the effect of the target material on the radiation furnishes information about the material. Here the application is based on detecting or measuring the radiation which penetrates or is reflected from the material. This presents an ideal setup for a testing procedure, especially since the amount of radiomaterial used is so small that the radiation does not alter the material under test. This type of use is the basis for most of the testing procedures now utilizing radioisotopes.

Tracing Materials with Radiation

In the third type of use (Fig. 1) the radioisotope serves as a tracer to follow the complicated course of material in bulk or the individual batches of atoms in chemical or biological reactions. The thing labeled and traced may be water running through a pipe, sugar being utilized in a human being, a raw product for milk production in a cow's body, or an atom transferring from one kind of molecule to another in a chemical reaction.

SIMPLICITY OF USE

These modes of use illustrate the simplicity of the principles involved. The basic requirements are a radiation emitter and a radiation detector. Lest this be an over-simplification, however, it should be emphasized that "emitter" and "detector" represent concepts which are far from simple. Even so, the materials and equipment needed for most applications, such as specially prepared sources, radiolabeled organic and inorganic compounds, shielding, and electronic circuitry, are readily available from commercial suppliers in as convenient forms as the manufacturer can make them. Further, the equipment and attendant services are continually being improved.

SENSITIVITY AND SPECIFICITY OF RADIOISOTOPES

Radioisotopes permit materials to be traced in minute quantities—a millionth to a hundred-millionth of the amount detectable by other means. It is easy to detect radiation from isotopes diluted with a billion or ten-billion times as much non-radioactive material. Some isotopes are detectable after dilutions of more than a trillion.

Even more important than sensitivity is the specificity of radioactive tracer atoms. They can label a specific batch of atoms and enable it to be traced through a series of chemical or physical processes. This permits the sorting out or untangling of complicated processes which can be followed in no other way.

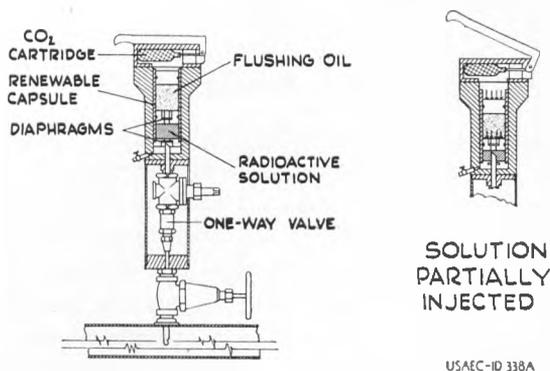
The sensitivity of radioisotope detection, the specificity of the tracer method, and the unique radiation characteristics of individual radioactive species permit radioisotopes to be used as powerful analytical tools in at least three major ways. These may be referred to as "tracer analysis", "isotope dilution analysis", and "activation analysis". The first two analytical techniques, as applied to hydraulic problems, are comparable in many ways to the salt-velocity method and the salt-dilution method, respectively.

EXAMPLES OF APPLICATIONS

Radioisotopes have been used to determine flow rate, volume, flow pattern, efficiency of separation, thoroughness of mixing, leakage, and other associated hydraulic problems. These determinations can often be made quite easily where other methods fail.

In many hydraulic applications of radioisotopes, a sharply defined peak in the counting rate must be obtained. It is essential, therefore, that the radioisotopes be injected quickly, in as small

a volume as practicable and without introducing air into the system. The radioisotope injector, shown in Fig. 2, illustrates one type of commercially available apparatus that meets these requirements [2]. The injector uses small CO₂ cartridges to inject the tracer and flushing liquid into the pipe in less than one second. In one particular use, 18 cc of tracer solutions and 36 cc of flushing solution are placed in a capsule in a radio-chemical laboratory. At the pipe-line site, the operator places the loaded capsule and a CO₂ cartridge into the injector housing on the pipe. By operating a trigger handle to release the CO₂ gas, the tracer may then be injected when needed.



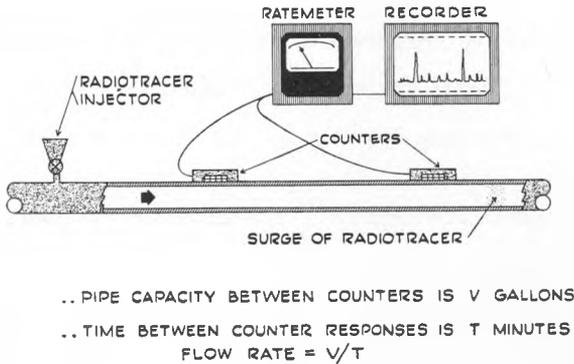
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FIG. 2. RADIOISOTOPE INJECTOR FOR PIPELINE FLOW PROBLEMS

Measuring Flow Rates

Two point method: The general method, illustrated in Fig. 3, for measuring liquid- or gas-flow rate is timing a surge of tracer between two points separated by a determinable volume [3]. This is most easily done on a straight section of pipe of known dimension, free from branch connections. The radioisotope is injected quickly, close to the point where it will be timed, in order to obtain a sharply defined peak in the counting rate as the tracer passes the counter. The counters at the two points are connected to a single amplifier so that they both record on the same chart. The flow rate is equal to the volume between the two counters divided by the time between the peaks.

Integrated count method: Radioisotopes can also be used to measure flow rate by recording integral counts [4]. This method, illustrated in Fig. 4, uses only one detector and eliminates the need for determining pipe volume. It is based on the principle that the total number of gamma rays registered by a radiation detector on

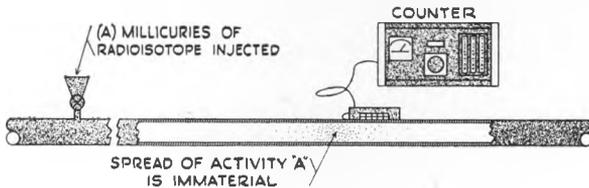


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FIG. 3. DETERMINING FLOW RATE BY PEAK TIMING USING RADIOACTIVE TRACER

a pipe passing a definite quantity of radioisotopes is inversely proportional to the flow velocity. Fewer counts are recorded when the isotope passes rapidly. The integrated count is independent of the variation in isotope concentration along the stream, as long as the flow rate is constant. The validity of the method is due to the sensitivity of the radioisotope method which permits measuring the longer tails of the build-up and fade-out curves that are undetectable with other tracers. To translate the total counts to an absolute determination of flow rate, it is necessary to calibrate the counting setup on a particular type and size of pipe involved. This is done by filling a cut section of pipe with a radiotracer solution at known concentration and measuring the counting rate under the same conditions as in field measurements. The counting rate depends on the concentration and may be expressed as:

$$\text{Counts/second} = \text{calibration constant} \times \text{millicuries/gallon}$$



COUNTING RATE DEPENDS ON CONCENTRATION
 COUNTS/SEC = CONSTANT * MC/GALLON
 TOTAL COUNT DEPENDS ON TIME OF PASSAGE
 COUNTS = CONSTANT * SEC * MC/GALLON
 THEREFORE, FLOW RATE IS GIVEN BY TOTAL COUNT
 GAL/SEC = CONSTANT * "A" * 1/COUNTS

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FIG. 4. MEASURING FLOW RATE BY INTEGRATED COUNT USING RADIOISOTOPE TRACER

The total count from the passing liquid depends on the time of passage and may be expressed by rearranging this equation as:

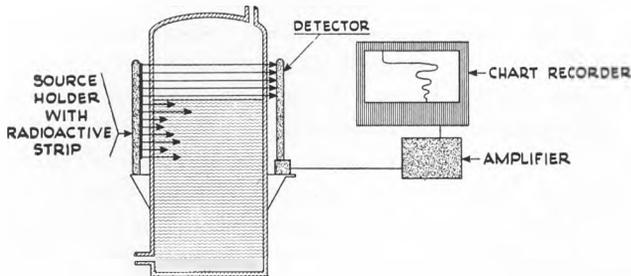
$$\text{Counts} = \text{constant} \times \text{sec} \times \text{millicuries/gallon}$$

Therefore, the flow rate is given by the total count and may be expressed as:

$$\text{gallons/sec} = \text{constant} \times \text{millicuries} \times 1/\text{counts}$$

Measuring Liquid Volume

Measurement of volume in a closed system under dynamic conditions may present difficult problems. However, radioisotopes readily lend themselves to these determinations in several different ways. They can be used both as external sources of radiation for liquid-level gaging and as radiotracers for calculating individual volumes in multiphase systems. In the latter case a mixing action either by external circulation or by internal stirring is necessary.



- .. DROP IN LIQUID-LEVEL EXPOSES MORE RADIATION
- .. PROVIDES CONTINUOUS MEASUREMENT
- .. ACCURATE LEVEL RECORDING WITHOUT CONTACT

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FIG. 5. LIQUID LEVEL GAGE, AN INDUSTRIAL USE OF RADIOISOTOPES

Liquid level gages, illustrated in Fig. 5, are perhaps the most common use of radioactive sources in hydraulic problems. As an example, the gamma radiation from radiocobalt has been used to determine the height or volume of molten metal in a cupola. The source is mounted on one side of the cupola and the radiation detector on the other side. By noting the intensity of the measured radiation, it can be easily determined whether the height of the material inside the cupola is above or below the height at which the source and the detector are set. The same technique has also been used to determine, under dynamic conditions, the height of

materials in high-pressure, high-temperature autoclaves and various other fluid systems. The primary advantage of this type of measurement is that it eliminates the effects of high temperature, high pressure, and corrosion on the gage.

Radiotracer dilution method: Another radioisotope method for determining volumes within closed systems is similar to the salt-dilution method well known to hydraulic engineers. Volume may be found by adding a known quantity of radioisotope to an unknown quantity of liquid. Samples are taken from the unknown volume after a steady state has been reached. By comparing these with standards prepared by dilution, total volume can be readily determined. This method, known as the isotope-dilution technique, is widely used by radiochemists and physicists. Due to the sensitivity of the radioisotope method a very small quantity of radioactivity can be used to determine accurately and economically the volume of large amounts of liquid.

Exponential method: Another radiotracer method is used to determine volumes within tanks or systems through which there is a known constant flow [4]. A radiotracer is put into the incoming line and complete mixing of the incoming stream with the vessel contents is assumed. Mathematically the tracer concentration in the tank falls off exponentially with a rate determined by throughput R and volume V as follows:

$$\frac{d \ln C}{dt} = -\frac{R}{V}$$

where C is the counting rate. The left-hand member is simply the slope of the straight-line plot of counting rate vs. time on semilog paper. The volume is therefore found from

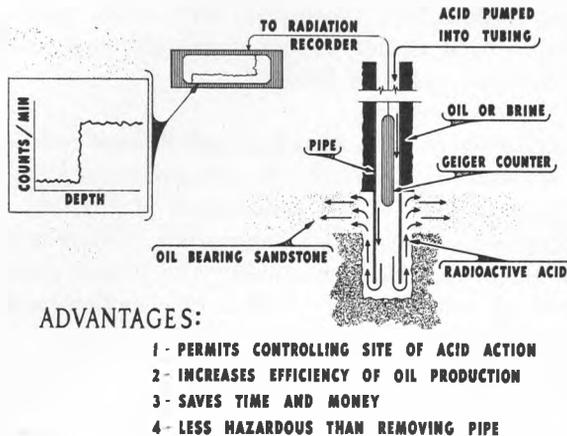
$$V = R/\text{slope}$$

Circulating-loop method: Volume of a circulating-loop system can be determined by a variation of the method for determining flow rate by peak timing, described above [4]. Here, however, the flow rates must be known in order to determine the total volume in the system. Also, it is essential that mixing be slow compared to circulation rate. A concentrated slug of radioactivity, quickly injected, is observed in repeated cycles. Time between successive tracer-peak appearances, multiplied by circulation rate, gives the total volume of the circulating liquid.

Tracing Flow Patterns

Control of liquid levels: In oil-well operations any means of obtaining information regarding conditions in the bore-hole has considerable economical significance. As an example, the rate of oil production depends to a large extent on the porosity of the formation. This porosity is reduced with age as particles of limestone are deposited in the interstices. When production drops to an uneconomical level, the well can be treated with hydrochloric acid under pressure to dissolve some of the carbonate and reestablish the flow.

If a radiotracer is added to the acid, as illustrated in Fig. 6, the operator may determine the depth of the acid level without



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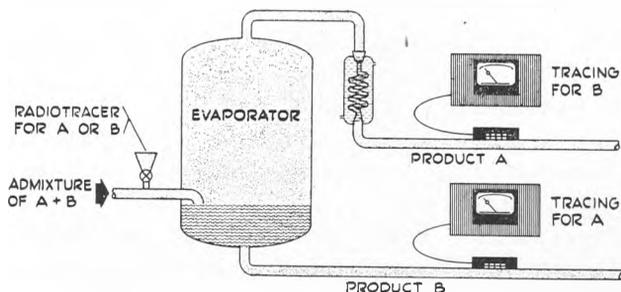
FIG. 6. RADIOACTIVE ISOTOPES FOR CONTROL OF OIL-WELL ACIDIZING

removing the sections of 2-inch pipe through which the acid has been pumped into the well. Once the acid has reached the level at which the radiation detector is suspended (at the formation to be treated), a signal indicates to the operator that pressure should be applied to force the acid through the oil-bearing strata.

Water flooding operations: In another oil-field use involving water flooding, radiotracers are injected into water-input wells and, after underground migration, are measured at surrounding oil-production wells [6]. These measurements have led to successful determination of relative rates and patterns of flow of injected water between water-input and oil-production wells and detection of zones of excessive water entry into oil-production wells.

Measuring Efficiency of Separation

Radioisotopes may be used to measure the efficiency of separation in complex systems [4]. For example, an admixture of products A plus B may be separated in an evaporator, as illustrated in Fig. 7. Radioisotope tracers for either A or B are injected into the evaporator feed line. To check for efficiency of separation a counter is attached to the pipe carrying the untagged separated product and the presence of any radioactivity is measured. Another counter attached to the pipe carrying the tagged products shows the radioactivity in that stream. By integrating the counts on both streams and making corrections for the different flow rates, a quantitative measure of the amount of cross-contamination of the products may be obtained.



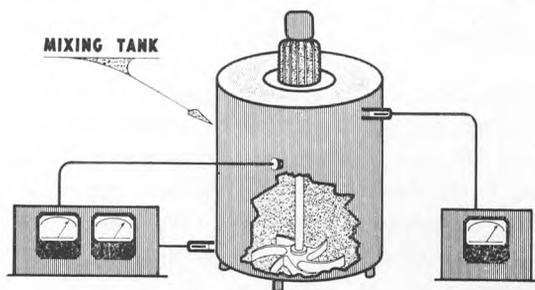
QUANTITATIVE MEASUREMENTS WHEN CALIBRATED
WITH STANDARD SAMPLES.

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FIG. 7. MEASURING EFFICIENCY OF SEPARATION USING RADIOACTIVE TRACER

Determining Uniformity of Mixing

Another possible application of the radioactive tracer technique is measuring uniformity of mixing. When large volumes of liquids are involved, sampling from all parts of the mixer may present many difficulties. By fitting radiation detectors in strategic places around the mixing tank and incorporating a short-lived gamma-ray-emitting radioisotope into one of the constituents, the concentration of that constituent at the various places can be compared. With this information, time of mixing necessary for a desired degree of uniformity can be determined. A simplified diagram of this possible method is illustrated in Fig. 8. The method could be readily used in either a continuous or a batch process.



ADVANTAGES:

1 - UNIFORMITY OF MIXING EASILY ASSURED

2 - EXCESSIVE MIXING TIME ELIMINATED

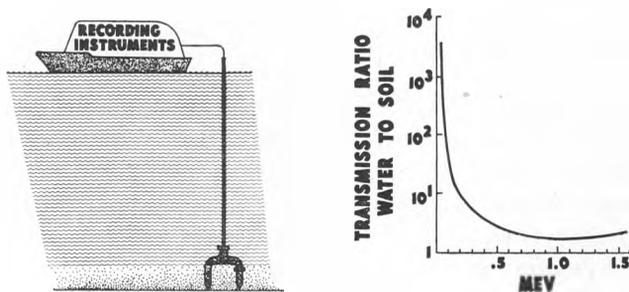
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FIG. 8. RADIOACTIVE ISOTOPES FOR DETERMINING THOROUGHNESS OF MIXING

Measuring Silt Density in Water

Measuring silt density in large bodies of water often involves major difficulties in access and sampling. Such measurements have been considerably simplified, however, by an interesting application of the radioisotope technique. A device for this particular application was developed jointly by the AEC Isotopes Division and the TVA [6].

Even the "softest" rays from available gamma-ray emitters penetrated water and water-saturated silt with nearly equal ease and thus did not distinguish between them. However, the easily absorbed X-rays, or bremsstrahlung, produced in a secondary process by beta-emitting isotopes, were found to give a satisfactory attenuation ratio between water and silt.



ADVANTAGES: 1-MORE ACCURATE

2-MEASUREMENTS EASILY AND QUICKLY MADE

3-ELIMINATES COLLECTING SAMPLES

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FIG. 9. BREMSSTRAHLUNG GAUGE FOR MEASURING SILT DENSITY

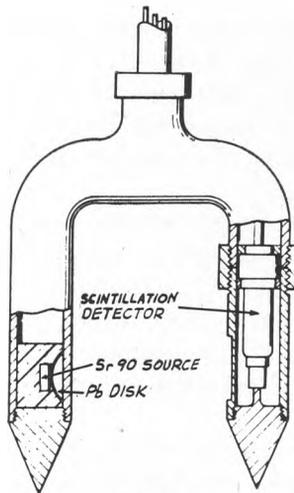


FIG. 10

The device which evolved, shown in use in Fig. 9 and detailed in Fig. 10, is a 2-pronged probe with a 20-millicurie Strontium 90 source in one prong and a scintillation counter 12 inches away in the other. Beta particles from the source produce the desired X-rays as they penetrate a lead disk. The counter is connected, through a long cable, to a counting-rate meter in the operator's boat or shore station.

The general principle and approach revealed in this application may easily be applied to many other hydraulic problems.

Leak Testing

Leaks of any liquid from one channel to another can be readily detected with radiotracers and, under the proper conditions, can be measured quantitatively. This technique has been widely used in detecting and measuring leaks in heat exchangers and other similar closed-liquid systems.

Perhaps the simplest application is the use of radioiodine or radiosodium in detecting leaks in buried pipes. In this case, a small quantity of radioisotope is introduced into the pipeline and followed by means of its radiation until it ceases to travel on leaving the otherwise closed system. In a number of instances this test has made it possible to find and repair leaks in a house or other building with a minimum disruption of the structure. Furthermore, the test gives quick and reliable results where other techniques often fail. A personal experience with a leak location prob-

lem illustrates the simplicity of the technique. A puzzling leak developed in a water pipe in an Oak Ridge church just prior to Christmas. The leaking pipe, beneath five inches of concrete, was spilling three gallons of water per minute into the foundation of the building. Cancellation of several Church activities in the building appeared imminent.

Before resorting to more drastic leak-location procedures, it was decided to try the radiotracer technique. A ten-gallon bucket of water, as illustrated in Fig. 11, was mounted on a ladder, and connected to an outside faucet through a garden hose. After closing the system at the water main, $2\frac{1}{2}$ millicuries of Iodine 131 solution were injected into the hose from a lead shielded syringe.

The only flow was thus from the elevated bucket to the leak and the radioiodine was, of course, carried with it. The radiation was easily detected and followed above the concrete floor until it came to a stop in the men's lavatory. After the water pipe was flushed to dispel any remaining radioactivity, a hole was cut into the floor at the indicated spot. The leak was found directly beneath it. The entire job cost less than \$10, whereas an estimated \$1000 to \$1500 would have been required by conventional methods.

POSSIBLE FUTURE USES OF RADIOISOTOPES

Recent developments in low-level radiation counting (counting just above the natural or background radiation level) hold considerable promise for a large number of additional applications. Using these very sensitive methods, tracer tests can be carried out during actual processing in a plant, and so little radiomaterial need be used that the products reaching the general public would be completely safe.

Special electronic circuits that cancel out the natural radiation background permit an easy measurement of harmless levels of radioactivity. Samples for measurement are usually placed directly inside the counter or the scintillation fluid.

Nature has herself shown how useful radioisotopes can be. For example, it is possible to distinguish recently living wood from wood long dead by virtue of radiocarbon produced through the action of cosmic rays on nitrogen in the air. Growing things absorb and use the radioisotope along with normal carbon. At death, absorption stops. Using the decay of these naturally occurring radioisotopes as a timing device, the age of archeological relics can be quite accurately determined. In a similar way, rain water



FIG. 11a. TO LOCATE A PUZZLING LEAK BENEATH THE CONCRETE FLOOR IN KERN METHODIST CHURCH, OSCAR BIZZELL INJECTS $2\frac{1}{2}$ MILLICURIES OF IODINE 131 FROM A LEAD SHIELDED SYRINGE INTO A GARDEN HOSE SERVING AS A PRESSURE HEAD. JAMES HITCH MONITORS THE OPERATION WITH A "CUTIE PIE" WHILE REV. G. WILSON ELLIOTT WATCHES.



FIG. 11b. HITCH WITH A SCINTILLATION COUNTER AND BIZZELL WITH A GEIGER COUNTER TRACK THE RADIOACTIVE SIGNAL ACROSS THE CONCRETE FLOOR. THE MORE SENSITIVE SCINTILLATION COUNTER WAS FOUND TO BE BEST SUITED FOR THIS TYPE OF MEASUREMENT.



FIG. 11c. AFTER TRACKING THE RADIATION THROUGH SEVERAL ROOMS AND AROUND BENDS IN THE PIPE, THE SIGNAL CAME TO A STOP IN A LAVATORY. A BULL'S EYE ON THE FLOOR INDICATES THE SPOT ABOVE THE LEAK.

can be distinguished from ground water by the radioactivity of naturally occurring radiohydrogen, or tritium, also formed by cosmic radiation.

Many progressive engineers are already using radioisotopes to solve a multitude of difficult problems. Recent developments in low-level counting techniques now make it possible to extend the use of radioactive tracers to many new problems in which they were previously considered too hazardous because of the amounts required. There is no doubt but that radioisotopes hold the key to many present-day hydraulic problems.

DISCUSSION

The discussion was initiated by Mr. Bauer who was interested in knowing whether the dilution technique, in which a known quantity of radioactive fluid is used, could be applied to measure discharge in rivers. Mr. Bizzell thought that the dilution would be so great for such a tremendously large volume of water that the method would be inaccurate, or that so great a quantity would be required that the cost would be prohibitive. The method should be restricted to pipe lines, basins, etc., or to determine dilution in

a river within a fairly short distance downstream. For example, he continued, at Oak Ridge, the natural waste from the Oak Ridge National Laboratory reactor is held for a "cooling" period in a settling basin and then dumped into the Clinch River. It is extremely difficult to find any trace of radioactivity in the waste even a short distance downstream.

Mr. McLean then remarked that a few years ago he had considered using radioactive isotopes in connection with some pump tests, but that at that time these isotopes were not available. He inquired whether such isotopes are available now and whether they could be used in an 84-inch pipe in which water for cooling condensers is being recirculated. In reply, Mr. Bizzell first called attention to the fact that one must consider whether or not the water is potable. The National Committee on Radiation Protection has rather stringent requirements about how much added radioactivity can be present. This is detailed in National Bureau of Standards Book 52, which lists the amount of various isotopes. Some radioactive isotopes are relatively non-hazardous, such as



FIG. 11d. AFTER THE LEAK IS REPAIRED, WATER SAMPLES ARE ANALYZED TO ASSURE THAT THE RADIOIODINE IS BELOW THE MAXIMUM PERMISSIBLE CONCENTRATION FOR DRINKING WATER. MAXIMUM PERMISSIBLE CONCENTRATIONS OF RADIOISOTOPES IN WATER ARE PUBLISHED IN NATIONAL BUREAU OF STANDARDS HANDBOOK NO. 52, AVAILABLE FROM THE U. S. GOVERNMENT PRINTING OFFICE, WASHINGTON, 25, D.C., PRICE 20 CENTS.

sodium 24 which is widely dispersed in the body and eliminated quite rapidly, whereas iodine 131 which goes straight to the thyroid gland and tends to stay there, is relatively hazardous. One could tolerate about 1000 times as much sodium 24 as iodine 131 in potable water. For Mr. McLean's application he suggested the use of sodium 24. Although radioactive isotopes are now available from the Brookhaven and Argonne laboratories, they are primarily available as processed materials from the Oak Ridge National Laboratory which can furnish over 100 different radioactive isotopes. He stated, further, that Oak Ridge has the function to license radioactive-isotopes for non-agency uses. The primary criteria for licensing are the experience of the prospective user in handling the materials and the safety factors involved. The materials can be readily obtained if assurance is given that the operator is sufficiently well-trained so that he will avoid accidental exposure, and that the precautions are such that none would be harmed by the radioactive isotopes. The materials are quite inexpensive. The material used to trace the leak was \$2.25 worth of radioactive iodine.

Mr. McLean then asked whether the trail-out part of the curve is obtained as the radioactive concentration is increased. Mr. Bizzell's reply was in the affirmative, that the dilution technique with radioactive-isotopes is more sensitive than with salt.

Mr. Bizzell then thought it would be of interest to mention that there have been recent developments in techniques of low-level counting, on which Dr. Libby, a member of the Atomic Energy Commission, has done considerable work. This opens up a tremendous field of application where a safe level of radioactive isotope is still measurable.

In conclusion, Mr. Bizzell mentioned some additional applications, such as the demarcation of the interfaces of oils in pipelines. It is possible, without actually injecting a radioactive tracer in a pipeline, to determine the location of an interface with great accuracy by using a radioactive source outside of the pipe and measuring the radiation reflected from the interface.

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