RADIOISOTOPES IN INDUSTRY

Radioisotopes have already revolutionized research in the biological sciences. Now they threaten to do the same in industry

by JEROME KOHL

TODAY, ONLY FOUR YEARS AFTER the first shipment of pile-produced radioactive materials from the Oak Ridge Laboratory of the Atomic Energy Commission, some 12,000 shipments of radioactive isotopes have gone out to more than 750 government, private and industrial laboratories for use in peacetime research.

More than 450 shipments of radioisotopes leave the Oak Ridge Laboratory each month. They go to all the countries of the world, for use in all the major fields of scientific investigation, and for applications in medicine, agriculture and industry as well.

The British physicist Frederick Soddy, in 1910, first applied the term isotope—from the Greek *isos* (same) and *topos* (place)—to substances with different atomic weights which nevertheless had identical chemical properties and occupied the same place in the periodic table of elements.

For example, carbon, as found naturally, consists of two isotopes of atomic weights of 12 and 13. Carbon-12 is stable and comprises 98.9% of all natural carbon. Carbon-13 is also stable and comprises the remaining 1.1%. Besides these two naturally occurring stable isotopes, radioisotopes of carbon can be produced with atomic weights of 10, 11, and 14. Carbon-10 has a half-life of 20 seconds (in other words, half the radioactive atoms will have disintegrated in that length of time). It emits a positron and becomes boron-10. Carbon-11 has a half-life of 20.5 minutes. It becomes boron-11 after emitting a positron. And the carbon-14, with a half-life of 5,100 years, forms nitrogen-14 with the emission of a beta particle.

Radioisotopes are useful because, while exhibiting the same chemical behavior as the stable isotopes of the same atomic number, they can be differentiated and located by their emitted radiation. In studying compounds formed during photosynthesis, for instance, carbon dioxide containing the radioactive carbon-14 is fed to plants. Products formed at varying times after introduction of the radioactive carbon dioxide are determined by analysis of the plant structure. Presence of the radioactive carbon-14 in any particular compound provides proof that it was formed from the radioactive carbon-14 and in the period following its administration.

Since radiations from individual atoms can be measured, radioisotopes make possible the detection of minute quantities of materials. For example, in friction tests, use of an activated sample permits determining the amount of metal transferred, even though this metal weighs under 10^{-10} grams. Radioactive sodium has been detected in amounts below 4×10^{-19} grams.

The radiations emitted by radioisotopes are in some cases extremely pentrating. Thus the tagged compound or object can be located at a distance or even through a steel wall. A burrowing animal, tagged with a small capsule containing a radioisotope of zinc or cobalt, can be followed as it moves beneath the ground. Go-devils, which are used for cleaning pipelines, can be tagged with a radioisotope permitting their location through the pipe wall.

Radioisotopes are also useful as sources of radiation. The alpha particles emitted by radioisotopes such as bismuth-210, ionize air and can be used for static dissipation. Beta particles, such as are emitted by strontium-90, are used in thickness gauges; in this application, the attenuation of these beta particles by the material to be measured provides an indication of its weight per unit area. Gamma rays, such as are emitted by cobalt-60, are used for treatment of cancer and for industrial radiography.

Progress in the use of radioisotopes was slow until the chain-reacting piles were constructed during the recent war. For workers in the 1920's only the naturally occurring radioisotopes were available.

The development of the cyclotron in the mid-30's made it possible to produce radioisotopes of many of the elements—but at enormous expense and on an infinitesimal scale. The uranium chain-reactors, since the war, have increased the available supply of radioisotopes by a factor of several thousand over those available from natural sources, cyclotrons and other accelerators. They have also greatly reduced the cost of radioactive materials. A single millicurie of carbon-14 produced in a cyclotron would cost $1,000,000; the same amount produced in the Oak Ridge Reactor is sold for $50.

There are now more than 700 known radioisotopes. More than 100 of these are available from the United States Atomic Energy Commission. But most of the interest and the applications have centered on the nine elements listed in the table below.

Pile Production of Radioisotopes

In a pile, radioisotopes are produced by two basic phenomena: (1) the fission of the uranium fuel; and (2) the absorption of neutrons by non-fissionable elements.

When uranium fissions, it breaks into radioactive fragments called fission products. These products range in atomic number from element-30 to element-64. In processing fuel that has been removed from the reactor, certain of the fission products are recovered either as elements or in groups.

While nuclear fission results in the production of many radioactive elements, the neutron capture reaction is the principal isotope producer. Normally, in the Oak Ridge pile, target materials for the capture reaction are inserted in ¾"-diameter x 3" long aluminum cylinders. These cylinders are then placed in a graphite block or "stringer," which is pushed into the interior of the pile and irradiated by neutrons for a given period. The target material can comprise an element or compound or even a fabricated article, such as a piston ring or corrosion specimen. When a fabricated article is irradiated, the activity is produced directly within the article. This makes the production of equipment or specimens from radioactive components unnecessary.

In the neutron capture or (n,gamma) reaction, a neutron is absorbed by a target atom and a gamma photon is emitted. This reaction produces radioisotopes which are isotopic with the target element. Thus, irradiation of stable sodium-23 results in the production by the (n,gamma) reaction of radioactive sodium-24.

Less common neutron absorption reactions are the transmutation reactions, such as the (n,proton) or (n,alpha). In the first of these, a neutron is absorbed by a target atom and a proton ejected. In the second, a neutron is absorbed and an alpha particle ejected. Both of these transmutation reactions result in the production of radioisotopes which are chemically different from the target atoms. In this case, the radioactive atoms can be separated as a carrier-free product. The (n,p) reaction in the pile results in good yields of carbon-14, phosphorus-32, and sulfur-35, and small yields of iron-59. The (n,alpha) reaction produces hydrogen-3 and argon-37.

The Atomic Energy Commission has set up certain prerequisites for the procurement of radioisotopes. The

COMMONLY USED RADIOISOTOPES

Isotope	No. of Shipments from Oak Ridge to 6-30-50	Half-Life		Energy of Emitted Radiation in MEV		Cost of Minimum Shipment
				Beta	Gamma	
IODINE-131	4,224	8	Days	.595 .687	.367 .080	$1.00/MC carrier free
PHOSPHORUS-32	3,810	14.3	Days	1.70	..	$1.10/MC C.F.
SODIUM-24	600	14.3	Hours	1.4	1.4	$12.00/15 MC
CARBON-14	586	5100	Years	0.15	..	$36.00/MC
SULFUR-35	270	87.1	Days	0.17	..	$2.40/MC as H_2SO_4 $6.00/MC as BaS
CALCIUM-45	192	180	Days	.25	..	$33.00/3.0 MC
POTASSIUM-42	195	12.4	Hours	2.0 3.6	1.4, 2.1 1.5	$12.00/125 MC
COBALT-60	183	5.3	Years	.3	1.16 1.30	$50.00/1st CURIE $5.00/Add'l CURIE
IRON-59	165	46.3	Days	.26 .46	1.1 1.3	$33.00/MC

NOTES: (1) MC = Millicurie. In this table defined as 3.7 x 10^7 disintegrations per second.
(2) Carrier Free = Represents pure radioisotope not diluted with stable isotope of the same chemical species.
(3) A handling charge of $10.00 is made for each shipment.

first, which covers equipment, requires that isotope users have available suitable counting and monitoring equipment, such as:

1 Scaler with Register and Timer	$450 to $750
1 Tube Mount	25 to 200
2 G-M Tubes	50 to 200
Calibrated Source	25 to 50
1 Laboratory Monitor (G-M Tube)	250 to 400
1 Portable Radiation Survey Meter (Ionization Chamber)	250 to 650
Lead Bricks and Containers	200 to 300
Minometers, Film Badges, Planchets	150 to 250
	$1400 to $2800

The second prerequisite covers training of technical personnel. The Atomic Energy Commission requires that a recipient of radioactive materials have obtained training and experience in their use in a laboratory employing radioisotopes, or have associated with him an individual so experienced. This training can be secured at the Oak Ridge Institute of Nuclear Studies in a 4-week training course, or by an intensive course at one of the commercial radiochemical laboratories.

Medical Applications

Medical workers have been in the forefront in using this new research tool—and 38% of the 1850 applications listed in the AEC's Summary of Isotope Distributions cover applications pertaining to medicine and biology.

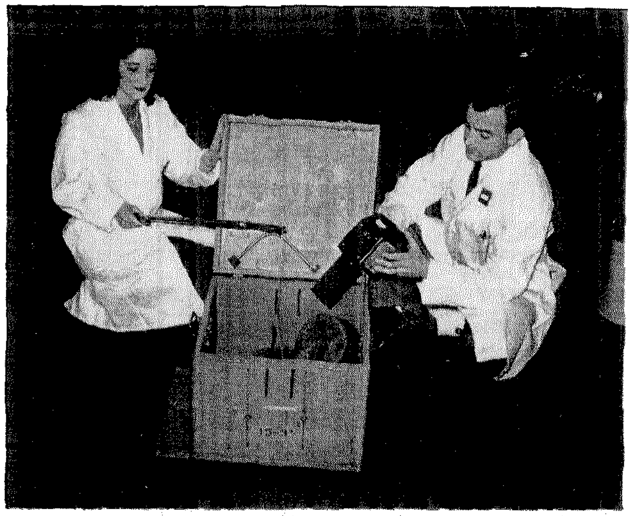
Phosphorus-32 is used to define brain tumors, utilizing the discovery that radioactive phosphorus concentrates in brain tumors in a ratio of 5 to 100 times the concentration in normal brain tissue. Iron-59 has been used to trace the distribution of iron through the organs and bodies of anemic rats in a fundamental attack on the causes of anemia. Iodine-131 is used in the treatment of certain thyroid disorders. Cobalt-60 is being used widely in place of radium for the treatment of cancer.

Industrial Applications

Industrial and engineering applications of radioisotopes are steadily increasing. The following examples cover some typical uses by industry and agriculture.

The feasibility of detecting radiation at a distance from the source has resulted in a number of interesting applications. At Cornell University D. R. Griffin, Professor of Zoology, has used radioactive materials in homing experiments with wild birds. The technique is to catch a bird at its nest, fasten a small capsule containing from 1 to 10 microcuries of zinc-65 to its leg (not enough to harm the bird), carry the bird a known distance from its nest, and release it. A radiation detection instrument hooked up to a clock or strip-chart recorder indicates the proximity of the bird and its time of arrival at the nest.

The Apis Engineering Company has used a similar technique for a different problem. It has tagged queen bees so as to cause the queen to operate swarming alarms. Activation of the alarm closes the hive exits and warns the bee-keeper. He can then guide the bees to a new hive.



Monitoring a shipment of barium-140 from Oak Ridge

The Physical Research Division of the Eli Lilly Company of Indianapolis, Indiana, reports that it is planning to tag ground moles with small quantities of radiocobalt in order to find out where they burrow, the distances they travel, and their general movement habits.

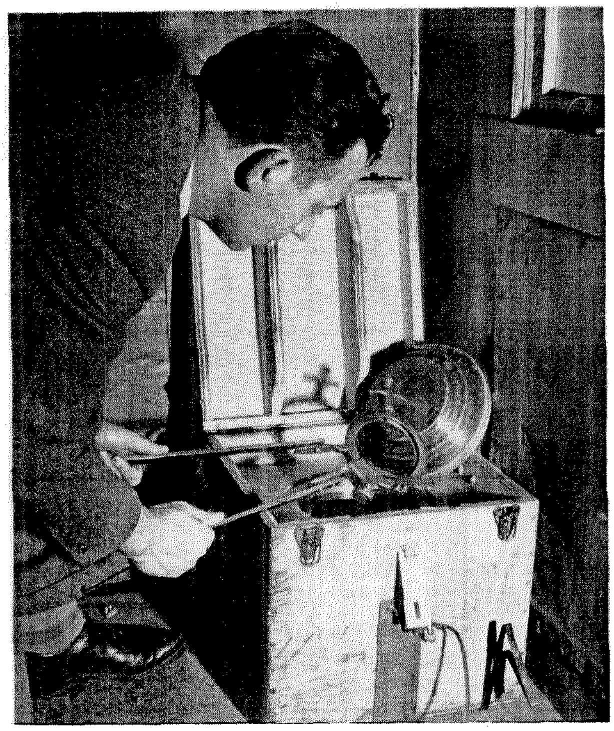
The feasibility of detecting very small quantities of a radioisotope makes it an ideal tool for cleansing action studies. J. C. Harris, R. E. Kamp, and W. N. Yanko incorporated carbon-14 in N,N-di-n-butyl stearamide, which is soluble in hydrocarbon oils. Test pans were dipped in oil containing the active compound and were then cleaned with various solvents, detergents, and rinses. The quantity of "soil" adhering to the metal following the cleaning cycle was determined by counting with a Geiger counter.

Calibration of the technique was obtained by counting a weighed amount of oil applied to a metal panel. The use of radioactive carbon permitted determination of quantities of "soil" below 2×10^{-7} grams per sq. cm., as compared with a maximum usual sensitivity by the gravimetric technique of 1×10^{-4} grams per sq. cm.

C. N. Birchenall and R. F. Mehl studied the rate of self-diffusion of iron in alpha and gamma iron by plating iron-59 on test specimens which were subjected to various heat treatments and then counted. Measurement of the rate of change of the surface count permitted calculation of diffusion rates.

In studying the rate of diffusion of silver in silver the General Electric Company has plated silver-110 on on the surface of a stable silver block, subjected the specimen to various heat treatments, and then shaved thin layers from the block for measurement of activity.

Calcium-45 has been used in the form of bicarbonate for studying the absorption and exchange of calcium during the washing of cotton swatches in the laboratory



Radioactive piston ring is removed from storage container for engine wear tests at California Research Corp.

of the General Aniline and Film Corporation. In the tests, actual conditions encountered in hard-water launderings were closely simulated. Labeled bicarbonate water corresponding to a hardness of 300 parts per million based on calcium carbonate was used. The calcium uptake was measured by placing the cotton swatches in a special sample holder, which exposed a definite area to a thin-window G-M tube. Calibration showed that calcium concentrations as low as 2 micrograms per gram of cotton can be detected readily in this manner.

Because the penetrating nature of gamma radiation permits its detection through pipe walls, barium-140 (a gamma emitter) has been used by Standard Oil of California to follow interfaces in oil pipelines. Ten millicuries of barium-140 were converted to an oil soluble barium soap and dissolved in a small quantity of oil. Aliquots containing 1 mc. each were injected into the pipeline at the time a stock change was made. Injection was accomplished by use of a compressed air cylinder. Travel of the interface was followed with a portable G-M counter. Location of this interface permitted tankage switching at the pipeline terminal at the optimum time. The technique also provided data on the degree of intermixing of materials pumped in the pipeline.

The ability to detect small quantities of a radioisotope permits its determination even when it is greatly diluted. S. Karrer, D. B. Cowie, and P. L. Betz took advantage of this dilution potential and injected sodium-24 as sodium chloride at a constant rate into the suction of a condenser water pump. Samples taken downstream from the condenser were analyzed for radioactivity content by use of a dip counter. The measured dilution, plus knowledge of the input rate of the activity, permitted calculation of the water circulation rate.

Even prior to the availability of the pile-produced radioisotopes, researchers at M. I. T. had been studying friction phenomena, using cyclotron-produced radioisotopes. In their early experiments, a copper-beryllium block was irradiated in the M. I. T. cyclotron, forming zinc-63 and copper-64. Test riders were then moved under controlled conditions over the activated surface and the quantity of transferred matter was determined by use of a Geiger counter. The effects of lubrication, load, and speed of movement were invesigated by this radioactive tracer method, which permitted detection of quantities of material as small as 10^{-10} grams.

In a more recent study, pile-produced radiochromium was plated on a piston ring. The ring was then installed in a test engine for study of wear under normal operating conditions. The distribution of transferred chromium was determined by autoradiographing the cylinder liner.

The pile irradiation technique has been used to study wear rate in an internal combustion test engine as a function of type of fuel, properties of lubricant, and jacket water temperature. The usual practice in conducting engine wear tests is to assemble the test engine with carefully weighed and measured components, operate the engine for a certain period, disassemble the engine for inspection and weighing of parts, reassemble, and continue. In some tests, the engine is disassembled several times during the run. The California Research Corporation used a piston ring which had been irradiated in the Oak Ridge pile to provide a continuous measurement of the rate of wear of the ring without requiring disassembling the engine. In the actual test, the rate of wear was measured by use of a dip counter immersed in the circulation lube oil. A correlation between counts per minute and weight of abraded material was obtained by counting a weighed amount of the metal.

Agricultural Applications

The ability to locate individual radioactive atoms and to differentiate these atoms from chemically similar stable atoms has resulted in a widespread use of radioisotopes for agricultural research. R. N. Colwell studied the drift of Coulter pine pollen by soaking the pollen in a water solution of Na_2HPO_4 using phosphorus-32. The rate of fall of the treated dry pollen proved to be the same as for that of untreated pollen. A calibration was obtained by counting a measured number of pollen. The labeled pollen was released in the field under conditions simulating its normal release from the tree. Later the pollen was collected along various radii from the point of release. Collections were made in petri dishes or by use of a vacuum cleaner. Use of photographic film in contact with the filters of the vacuum cleaner permitted locating individual radioactive pollen grains. In an experiment using 10 mc. of P-32 (which costs about $5.00), some 10 billion pollen grains were activated.

In a similar experiment by John C. Bugher and Marjorie Taylor, mosquitoes were grown in a medium containing phosphorus-32 and strontium-89. In field experiments, radioactive mosquitoes were released and catches made at a series of stations placed around the compass and at various distances from the release point. The experiments indicated that the mosquitoes were distributed largely by wind drift, rather than by their own flight.

Radioisotopes are ideally suited as tools for the investigations of fertilizers. Important plant nutrients, such as calcium, phosphorus, iron, postassium, copper, sodium, sulfur, and zinc are available as radioisotopes from the Atomic Energy Commission. These elements can be incorporated in fertilizers and applied to the soil to determine the effect on plant utilization of fertilizer composition or the method of application. Plant uptake of the activated fertilizer can be readily measured and can be distinguished from uptake of the same compound already present in the soil. The United States Department of Agriculture in Beltsville, Maryland, has studied a number of fertilizers in this manner.

X-ray gauges have been used for the past several years in steel mills for measurement of the total thickness of the steel. The gauges comprise an X-ray source and some type of radiation-measuring receiver.

For materials weighing under 1 gram per sq. cm. (0.050 inches of steel or 0.166 inches of aluminum), beta radiations such as are emitted by yttrium-90 and rhodium-106 can be used for thickness measurement. The Beta Gauge comprises a radioactive source, which is located under the material to be measured, and a receiver, such as an ionization chamber, which is mounted directly over the source. The material to be measured passes between the source and the receiver and acts as an absorber for the beta rays.

The Beta Gauge is truly a weight gauge, since the absorption of beta particles is a function of weight of absorber per unit area rather than thickness. Beta Gauges of the absorption type can be used for measuring the weight per unit area of materials such as paperboard, roofing felt, plastic sheet, or aluminum sheet.

Workers at California Research Corp. monitor a pipeline to detect presence of radioactive material

Thickness Applications

Where access is available to only one side of a sheet, or where very thin materials or coatings are to be measured, a backscattering technique can be used. When beta particles from a radioisotope impinge on a solid material, the direction of travel of a certain proportion of the impinging particles is changed. The magnitude of this effect is determined by the density of electrons in the solid material. Thus, the technique can be used to measure the thickness of a plastic sheet as it passes over a steel roll or the thickness of tin plate applied to steel sheet.

Another interesting thickness application is the measurement of water content of the snow pack by the use of radioactive materials. This work is being carried on as the Cooperative Snow Investigations of the United States Department of Commerce, Weather Bureau, financed by the United States Army Corps of Engineers. In this study, radioactive cobalt-60 is located on the ground, while the receiver is located on a post above the activity. Transmitting equipment is used to send data regarding the weight of the snow pack to a central laboratory.

Radium has been widely used since the First World War for radiography of castings and welds. Radium currently costs approximately $20,000 a curie; cobalt-60 is now available from the Atomic Energy Commission at $50.00 the first curie and $5.00 a curie thereafter. The gamma radiations emitted by the cobalt-60 are very similar in energy to those emitted by the much more expensive radium. In addition to having the price advantage, cobalt-60 is free from the health hazard resulting from the emission of gaseous radon by radium. Accurate radiography requires compact sources. Cobalt-60 is now available in the form of irradiated wire, with a specific activity in curies per cubic cm. greater than that available from the presently used radium compounds.

It is obviously impossible to detail the hundreds of uses of isotopes. This cross-section sampling, however, should give some indication of the sensitivity, versatility, performance and promise of this revolutionary new research tool.