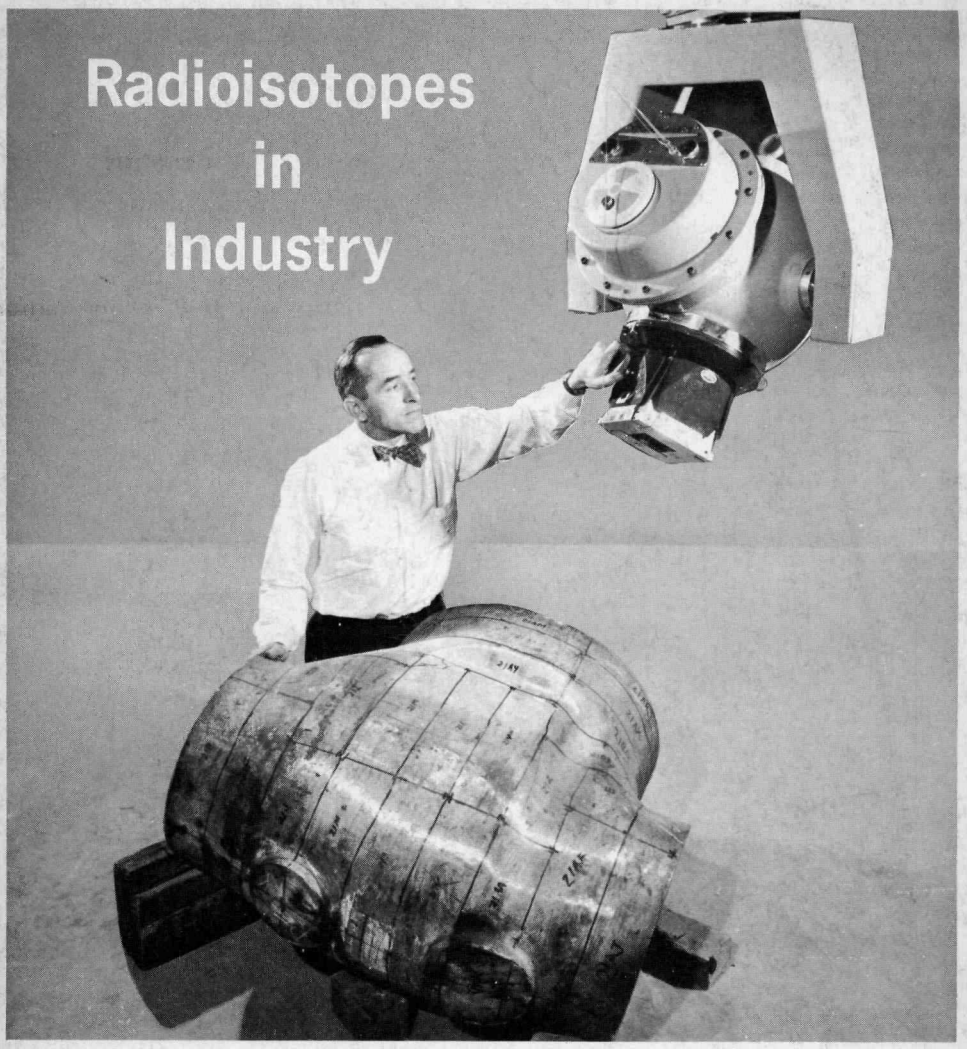
# Radioisotopes in Industry



U.S. ATOMIC ENERGY COMMISSION / Division of Technical Information

ONE
OF A SERIES ON
***UNDERSTANDING THE ATOM***

UNITED STATES
ATOMIC ENERGY COMMISSION

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Nuclear energy
is playing a vital role
in the life of
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in the United States today.
In the years ahead
it will affect increasingly
all the peoples of the earth.
It is essential
that all Americans
gain an understanding
of this vital force if
they are to discharge thoughtfully
their responsibilities as citizens
and if they are to realize fully
the myriad benefits
that nuclear energy
offers them.

The United States
Atomic Energy Commission
provides this booklet
to help you achieve
such understanding.

Edward J. Brunenkant
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# Radioisotopes in Industry

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*Radioisotopes are a mainstay of many important industries. Here, workers in an instrument-manufacturing plant are testing equipment.*

# Radioisotopes in Industry

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## DETECTABLE MORSELS

According to Sir Charles Snow, the noted scientist–writer, the "Scientific Revolution" began about 30 years ago, when atomic particles were first used in industry. Man-made radioactive elements (radioisotopes) have been serving industry on a routine basis half that long. Their usefulness today is not in fanning the flames of a "revolution"—although they unquestionably contribute to our scientific progress—but in helping manufacturers make high quality products at low cost.

Radioisotopes are used in industry primarily for measuring, testing, and processing. How and why they are useful is the subject of this booklet. We will learn something of their origin, their properties, and, most important, their uses. Finally, we will see how they may be used tomorrow.

One property of radioisotopes that makes them valuable is that they are detectable in extremely small amounts. Their detectability recalls an unconfirmed story about George Hevesy, a pioneer in the development of radioisotope tracers. (In 1911 Hevesy had worked in the English laboratory of Ernest Rutherford, one of the early leaders in the study of radiation.) Hevesy ate in a boarding house, and he began to wonder whether his landlady was making stew out of food left over from the day before. To find out, he put a small amount of a radioisotope on his uneaten

food. When he examined the stew the next day with a counting instrument, he found that some of its ingredients had, indeed, come from scraps on his own plate!

Today isotopes are so common that they are familiar materials in many industries. Once in a while, however, they still appear in surprising and unexpected places. For example, a radioactive form of the noble or inert gas, krypton, can help detect impurities in the air. In one type of smog alarm, krypton is "caged" in a crystalline chemical. When sulfur dioxide, a notorious air pollutant, enters the alarm device, krypton is released as a result of chemical action. The gas is scanned by a Geiger counter, and the number of radioactive disintegrations recorded gives a fair idea of how much sulfur dioxide displaced the krypton (Figure 1). Information from a series of these devices

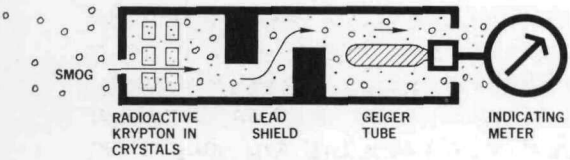


**Figure 1** *Schematic drawing of radioactive krypton-85* smog alarm.

placed strategically above a city can alert industry and government officials to order cutbacks on smoky operations, leaf burning, and other smog-causing activities.

It is of course true that radioisotopes have many properties besides detectability which make them useful in industry. We will learn about their other properties as we learn how they help people in our society.

## EXPLAINING RADIOISOTOPES

### Our Atomic World

All matter consists of very tiny particles called *atoms*. As small as they are, atoms have their own building blocks. These still smaller particles are: protons (positively charged) and neutrons (uncharged), which occur together at the center of the atom and make up its *nucleus;* electrons (negatively charged) move rapidly in a cloud, or shell, surrounding the nucleus at a great distance in relation to the nucleus size.

All atoms have protons and electrons. The simplest of all atoms is the hydrogen atom, which has a single proton in the nucleus. For every proton in the nucleus, there is an electron orbiting around the nucleus.

All atoms except hydrogen have neutrons also, which add to the weight of the nucleus. For example, normal helium has two protons and two neutrons in its nucleus; common carbon has six protons and six neutrons. What is particularly important is that for any fixed number of protons (the number that defines the element) there can often be several different numbers of neutrons. This difference accounts for what are known as *isotopes*, which are atoms differing from each other only in the number of neutrons in their respective nuclei.

Let us look at the isotopes of the simplest element, hydrogen. Simple hydrogen has one proton and one electron; heavy hydrogen, or deuterium, has one proton and one neutron plus an electron; and very heavy hydrogen, or tritium, has one proton and two neutrons plus an electron.*

## From "Unhappy Nuclei" to "Twinkling Atoms"

Each isotope has some fixed ratio of neutrons to protons in its nucleus. If this ratio falls within rather narrow limits, the nucleus seems to be quite "happy", or stable. However, if the ratio is either above or below these limits, the nucleus becomes "uneasy", or unstable; it then undergoes a rearrangement that results in a different kind of atom with a new and stable neutron-to-proton ratio. During this rearrangement the isotope gives off radiation, and it is therefore called a *radioisotope*. It might be termed a "twinkling atom".

Most nuclear rearrangements result in the ejection of alpha ($\alpha$) particles, beta ($\beta$) particles, or gamma ($\gamma$) rays. Alpha particles are helium nuclei (two protons and two neutrons) and have relatively large masses but very little penetrating power; they can be stopped by a piece of paper. Beta particles are electrons emitted from the nucleus and

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* For more basic information on atomic science, see *Our Atomic World*. For meanings of unfamiliar words, see *Nuclear Terms, A Brief Glossary*. Both are companion booklets in this series.

are much smaller than alpha particles (about 1/2000 the mass of a proton). Although they are more penetrating than alpha particles, they are completely stopped by thin pieces of wood. Gamma rays, which are electromagnetic radiations similar to ordinary light, can penetrate considerable thicknesses of even dense materials.

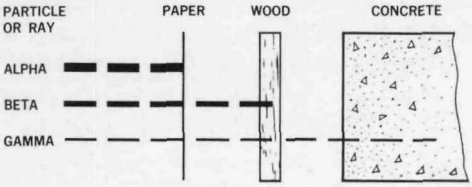


**Figure 2** *Relative penetration of alpha, beta, and gamma radiation.*

A characteristic of radioisotope rearrangement, or decay, that is extremely important is the *half-life*. This is defined as the amount of time it takes half of any amount of a particular isotope to disintegrate, or decay, to a stable form. For isotopes used for heat or power sources, radiography, and chemical catalysis, long half-lives are needed so that the isotope need not be replaced frequently. For tracers, isotopes with short half-lives are usually desirable so that the radioactivity will disappear soon after it has performed its service.

## Production

The atoms of a few natural elements have unstable nuclear arrangements; that is, they are naturally radioactive isotopes. A small amount of all potassium—including that in the human body, for example—is potassium-40, which is radioactive. For the most part, however, radioisotopes are produced artificially (1) by the addition of neutrons and/or the removal of protons, (2) by the addition of protons and/or the removal of neutrons, or (3) by *fission*—that is, the addition of a neutron to a large atom, thereby splitting the nucleus into chunks that are radioisotopes (Figure 3). The first and third types are usually carried out in reactors, while the second type is more characteristically produced in accelerators.*

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*For more about these devices, see *Nuclear Reactors* and *Accelerators*, companion booklets in this series.

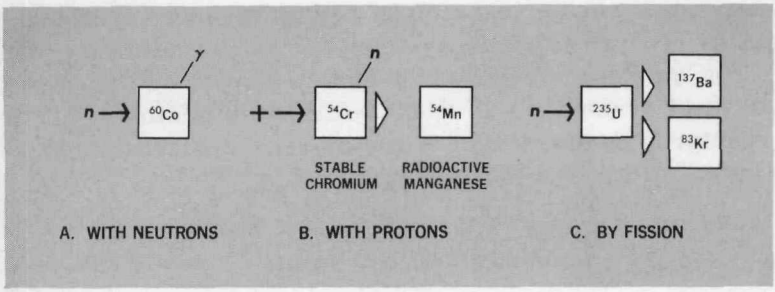



**Figure 3** *Production of artificial radioisotopes.*

Figure 4 shows common nuclear reactions for production of radioisotopes and gives examples. At present only

Figure 4—REACTIONS FOR RADIOISOTOPE PRODUCTION*

| Basic reaction | Example |
|---|---|
| (n,$\gamma$) | $^{59}$Co(n,$\gamma$)$^{60}$Co |
| (n,p) | $^{14}$N(n,p)$^{14}$C |
| (n,$\alpha$) | $^{6}$Li(n,$\alpha$)$^{3}$H |
| (n,fission) | $^{235}$U(n,fission)$^{137}$Cs |
| (p,n) | $^{65}$Cu(p,n)$^{65}$Zn |
| (p,2n) | $^{68}$Zn(p,2n)$^{67}$Ga |
| (p,pn) | $^{55}$Mn(p,pn)$^{54}$Mn |
| (p,$\alpha$) | $^{25}$Mg(p,$\alpha$)$^{22}$Na |
| (p,2p) | $^{58}$Ni(p,2p)$^{57}$Co |

*The designations used here are a standard "shorthand" for nuclear reactions. The letters inside the parentheses represent the participants in the reaction. The symbol before the comma is the "bullet" that strikes the nucleus to start the reaction, and the symbol after the comma is the radiation of particle(s) resulting from the reaction. Thus "(n,$\gamma$)" means "a neutron strikes the nucleus, and a gamma ray is emitted"; "(p,pn)" means "a proton strikes the nucleus, and both a proton and a neutron are emitted". The first example, written out more fully with chemical symbols would be $^{59}$Co + n → $^{60}$Co + $\gamma$.

about 100 radionuclides are produced regularly. Nearly 1500 have been identified, but most have half-lives that are too short for them to be useful. Perhaps 200 to 300 are potentially useful and would require only some technical development to make them available at reasonable cost.

## Properties That Make Them Useful

To use radioisotopes, men take advantage of their radiations in one way or another. Let us consider each of four important properties briefly.

**1. RADIATION TRACES MATERIALS** Whenever an unstable nucleus undergoes a rearrangement to become more stable (decays, or disintegrates), detectable and measurable amounts of radiation are given off. This radiation usually consists of gamma rays (very short electromagnetic radiation) or beta particles (electrons). These atoms can be located easily with suitable detection equipment. Use of a radioisotope to follow a material as it moves through a process is commonly called the *tracer technique.*

**2. MATERIALS AFFECT RADIATION** Since most of the radiations are more energetic than ordinary light, they can pass through opaque materials. Even so, not all the incident radiation necessarily passes through, since the amount that penetrates depends on the density and thickness of the material and the energy of the radiation. This is the basis for using radioisotopes in measuring thicknesses, finding voids (empty spots) in metal castings, testing welds, and taking pictures of concealed objects, such as bones inside the body or contents of sealed containers.

**3. RADIATION AFFECTS MATERIALS** Just as we may be sunburned from overexposure to sunlight, a person also may be burned by overexposure to gamma radiation from radioisotopes. This energetic radiation is capable of killing bacteria and insects; hence radioisotopes can be used for sterilization of materials and foods. The radiant energy is also suitable for catalyzing chemical reactions or supplying the energy to start them.

**4. RADIATION HAS ENERGY** The radiations from unstable nuclei have considerable energy, and it is not difficult to convert this energy to heat and electricity. When gamma rays or alpha or beta particles are stopped by being absorbed in a dense material, the energy is converted to heat, which can be transformed to electricity with thermocouples. This property is the basis of radioisotopic power

RADIOISOTOPE USES

| TRACERS | RADIATION AFFECTS MATERIALS |
|---|---|
| Flow measurement | Catalysis |
| Friction and wear | Use of radioactive catalysts |
| Isotope dilution | Improvement of catalysts |
| Labeled reagent | Fiber modification |
| Material tracking | Fission-energy-induced reactions |
| Preparation of | "Chemonuclear reactions" |
| tagged materials | Food preservation |
| Radiometric analysis | Growth acceleration |
| Reaction mechanism | Growth inhibition |
| Chemical reactions | Insect control |
| Metabolism studies | Sterile-male technique |
| Separation | Disinfestation |
| Filtration | Luminescence |
| Distillation | Mössbauer effect |
| Electrolysis | Polymer modification |
| | Polymerization |
| | Radiolysis |
| | (Chemical decomposition) |
| MATERIALS AFFECT RADIATION | Seed mutation |
| | Static elimination |
| | Sterilization of pharmaceuticals |
| Measurement and control | and medical equipment |
| Density gauges | Synthesis |
| Level gauges | X-ray fluorescence |
| Neutron gauges | |
| Thickness gauges | |
| Radiation absorptiometry | RADIATION HAS ENERGY |
| Radiography | |
| Secondary radiation effects | |
| Scattering | Heat sources |
| Bremsstrahlung | Power sources |

sources for lighting beacons, for operating unmanned weather stations, and for doing other important tasks.*

## Balancing Risk and Benefit

The use of radioisotopes introduces some hazards, but these are no more serious than those connected with many other commercial products we deal with daily. The nuclear industry has an excellent safety record. None of the seven

*For more about these uses of radioisotopes, see *Direct Conversion of Energy* and *Power from Radioisotopes*, companion booklets in this series.

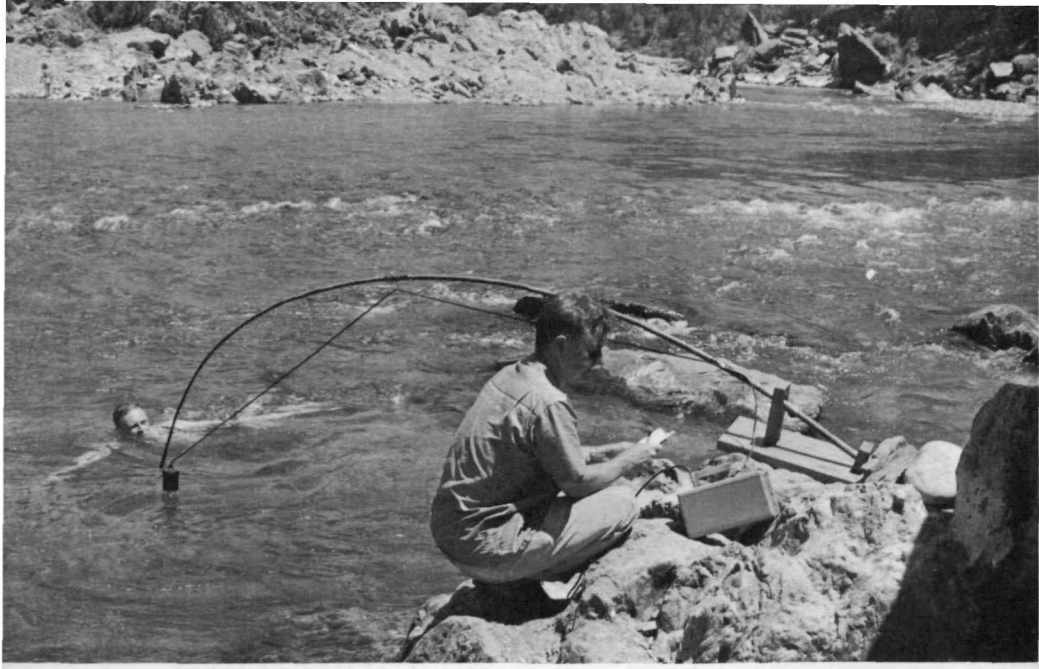


**Figure 5** *Studying flow of the American River in California with radioactive gold. The amount of tracer needed for this measurement is harmless.*

radiation fatalities in the industry's first 20 years resulted from use of isotopes.

A few persons are afraid of radioisotopes, however, or say they are. Most of their fear is a carry-over from the awesomeness of the military use of atomic energy. Apprehension also results because no one can see, hear, feel, taste, or smell radiation. We should remember, however, that easily available sensing and detecting devices are thoroughly competent to do what our senses cannot do in this case. There need be no fear of being unable to locate the rays and, with proper shielding, no fear of exposure to them during manufacture, packaging, shipping, or use.

## Drawbacks Do Exist

There are a few disadvantages—manageable ones, but real enough—associated with the industrial use of radioisotopes. These are:

1. Although small, harmless quantities of radioisotopes can be used for many purposes under the Atomic Energy Commission's "General License Provision", the use of

larger quantities requires special licenses from the AEC. Obtaining one of these licenses involves considerable effort, primarily in providing absolutely safe handling facilities. (Members of the public may possess the amounts of isotopes shown in Figure 6 without a special license.)

2. Radioisotopes, in contrast to X-ray machines, cannot be "turned off". This is sometimes a nuisance, but the inconvenience can be avoided by proper design of radioactive sources, "shutters", containers, and handling equipment.

3. For large quantities of radioactivity, such as those used for food irradiators and heat sources, shielding may be heavy and expensive. Again, proper design and choice of material will help.

4. The user must guard against accidental contamination if radiation sources are used. Handling facilities must be easy to clean in case leaks should occur. On the other hand, contamination from the use of tracer radioisotopes is a calculable event and can be controlled satisfactorily by choice of suitable tracer quantity and half-life. The radiations from radioisotopes do not as a rule make other substances radioactive since gamma rays are no different from light rays in this respect.

5. A minor disadvantage involves the effects of radiations on materials. In the case of labeled compounds used as tracers, the radiations "attack" the substance in which they are incorporated and decompose it. Similarly, careful control of amounts is necessary to prevent decomposition when radiations are used to catalyze chemical reactions.

Figure 6 — TYPICAL GENERAL LICENSE QUANTITIES OF RADIOISOTOPES

| Isotope | Quantity, microcuries* | Isotope | Quantity, microcuries* |
|---|---|---|---|
| Antimony-124 | 1 | Iridium-192 | 10 |
| Arsenic-77 | 10 | Iron-55 | 50 |
| Barium-140 – Lanthanum-140 | 1 | Iron-59 | 1 |
| Cadmium-109 – Silver-109 | 10 | Phosphorus-32 | 10 |
| Calcium-45 | 10 | Potassium-42 | 10 |
| Carbon-14 | 50 | Promethium-147 | 10 |
| Cesium-137 – Barium-137 | 1 | Silver-111 | 10 |
| Chromium-51 | 50 | Sodium-22 | 10 |
| Cobalt-60 | 1 | Strontium-90 – Yttrium-90 | 0.1 |
| Copper-64 | 50 | Sulfur-35 | 50 |
| Gold-198 | 10 | Technetium-99 | 1 |
| Hydrogen-3 (Tritium) | 250 | Yttrium-90 | 1 |
| Iodine-131 | 10 | Zinc-65 | 10 |

*A microcurie is the amount of radioactive material that has the same intensity of radiation as one millionth of a gram of radium.

**Figure 7** *Handling radioisotopes inside a* hot cell. *The operator uses remotely controlled tongs to pour radioactive material (left) into test tube.*

# GAUGING

## The Dead Sea Scrolls and Space Exploration

A modern "prophet", using scientific background knowledge, asserts that radioisotopes can help us to prepare paper for a book like this one which will last 20,000 years—10 times as long as the Dead Sea Scrolls lay buried before they were found in 1947. That prediction is based on research with a radioisotope, carbon-14. It is only a prediction, but here is a fact: The chances are that the paper in this book—like any paper product you pick up nowadays—was atom-inspected. For several years large paper manufacturers all over the world have been using isotope gauges to "feel" the thickness of paper while it is rolled out by machines operating at "runaway" speed.

Man, in his quest for finer and finer instruments, has improved the sensitivity of his measurements from an exactness within an inch or two to less than a millionth of that amount (Figure 8). Devices used in many modern industries measure products accurately to tolerances of a few hundred-thousandths of an inch, about the diameter of a human hair. In a few industries even greater accuracy is required, such as a millionth of an inch, an amount that has been described as "the distance a railroad rail would sag if a fly landed on it".

One type of isotope gauge, the thickness gauge, though as busy as a workhorse, is so inconspicuous that you could miss it in visiting a factory where it is used (Figure 9). It usually consists of a box containing a radioisotope (such as cesium-137), a radiation detector, and an indicator. The

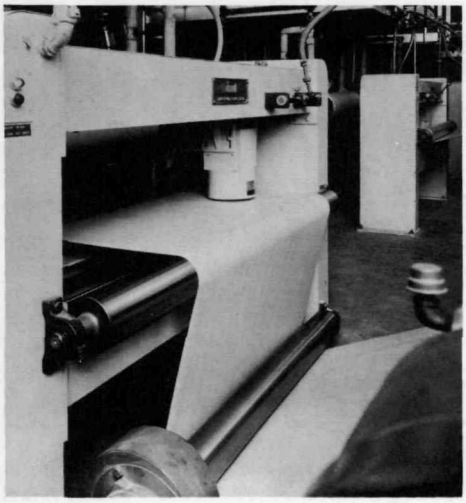


**Figure 9** *Radioisotope thickness gauge in use in a rubber factory.*

material being measured passes in a sheet between the radioisotope source and the detector. The action of this gauge may be compared to the action of sunshine on your eyes: The amount of light reaching your eyes depends partly on whether or not you are wearing sunglasses and, if you are, how dark the lenses are. Similarly, the amount of radiation reaching the thickness-gauge detector is proportional to the thickness and density of the sheet of material that separates it from the source of radiation (Figure 10). The measurements are recorded by a meter on a chart. Instruments now in commercial use detect and record variations in the thickness of paper or other sheet material rushing by at hundreds of feet a minute.

In a refinement of this instrument, an electronic signal from the detector may be fed back by a servomechanism to control the thickness of the sheet remotely by changing a roller setting. Thus the isotopic device can not only measure and monitor the thickness of material continuously but can also control it.

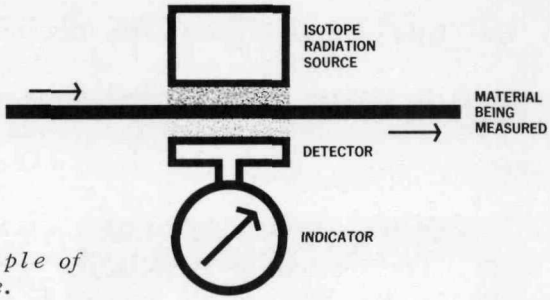



**Figure 10** *Principle of the thickness gauge.*

Let us examine the problem of a manufacturer of sandpaper who wants to be sure enough abrasive sand is getting on the paper. Of course he can, in effect, do what the boy with the clock did: stop the machinery, slice off pieces of sandpaper at different places along the production line, and test them. Sometimes this may be a good method, but it is time consuming and often inconvenient. Furthermore, the pieces cut off would give our manufacturer only a limited view of the whole process because of the random sampling, and the pieces themselves would be wasted product.

The manufacturer can solve his problems (Figure 11) with radioisotope gauges. The critical steps in the process are: (1) applying first adhesive, (2) applying abrasive, (3) partial curing in an oven, (4) applying final adhesive, and

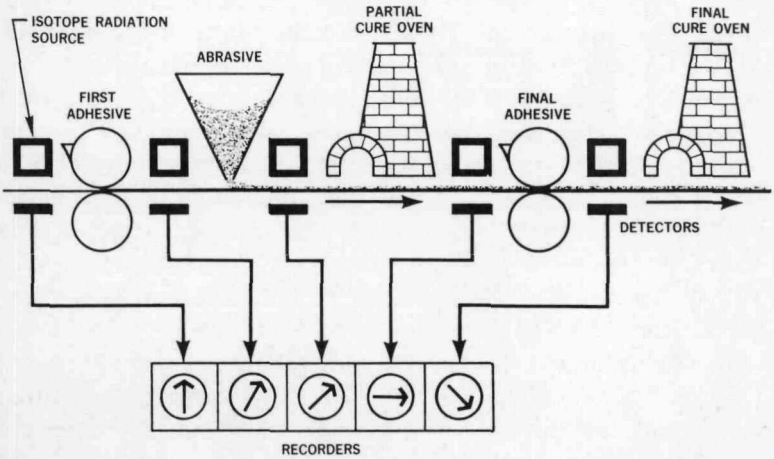



**Figure 11** *Use of multiple radioisotope gauges with remote controls.*

Manufacturers take these pains in measurement so that their products will be uniform. Uniformity is necessary in all mass production. It is vital in precision manufacturing to assure the proper performance of such equipment as space-exploration missiles, in which as many as 300,000 parts, made at hundreds of different places throughout the country, must be incorporated. With that many interdependent parts, a missile that has components even 99.9999% reliable is not good enough; statistical analysis tells us such a missile would have only a 50-50 chance of making a successful flight.

Figure 8—MEASUREMENTS THROUGH THE AGES*

| Unit or method | Era | Accuracy |
|---|---|---|
| Yard (King's arm) | 3000 B.C. | 1 to 2 inches |
| Barleycorn (length of grain—$\frac{1}{3}$ inch) | 14th Century | Tenth of inch |
| Micrometer | 17th Century | Thousandth of inch |
| Johansson gauge blocks (steel standards) | Late 19th Century | Hundred-thousandths of inch |
| Interferometry (beams of light) Radioisotopes (radiation) | 20th Century | Millionth of inch |

*Modified from *Precision, A Measure of Progress,* General Motors Corporation, 1952.

## Gauging Without Contact

How do you check 300,000 parts for uniformity as they are being made? Everybody has heard of the boy who takes a clock apart to see what makes it tick and cannot put it together again. This is an example of "destructive testing", which obviously does not always work. There is another way called "nondestructive testing". A physical checkup by a doctor is an example of nondestructive testing of a person's health or bodily soundness. Similar methods are becoming increasingly important in industry.†

†For more about this method, see *Nondestructive Testing,* a companion booklet in this series.

(5) final curing. By placing gauges between these steps, he can control the amounts of adhesive and abrasive to make sandpaper with different roughnesses and with a more uniform surface.

## Other Radioisotope Gauges

A problem similar to that of the sandpaper manufacturer is the measurement of a thin layer of one substance adhering to a backing material of another. Knowing how much tin is used to coat steel sheet, for example, is vital in a tin-can factory. The manufacturer can measure the thickness of the tin with isotopes by backscatter gauging or with X-ray fluorescence.

The principle of the backscatter gauge is similar to that of the thickness gauge. Radiation is scattered when it strikes any material. The thicker the material, the more radiation is scattered, up to a point. In a backscatter gauge the detector is shielded from all but the scattered radiation; therefore the more radiation striking the detector, the thicker the material is (Figure 12). As with a thickness gauge, the indicator and recorder give a running account

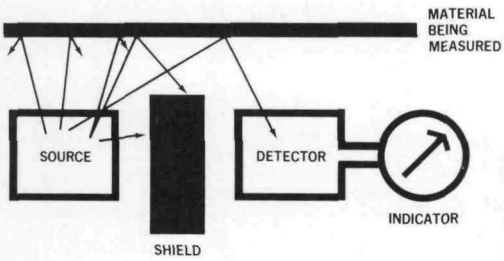



**Figure 12** *Principle of the backscatter gauge.*

of small thickness variations. This gauge is also used to measure materials like steel pipe wall and other products for which a two-sided thickness gauge is unsuitable.

In X-ray fluorescence the radiation excites both the coating and the backing to produce X rays that are characteristic of the elements of which these materials are formed (Figure 13). As the coating material is excited, the intensity of the induced radiation increases with the thickness of the coating. When the backing is excited, the in-

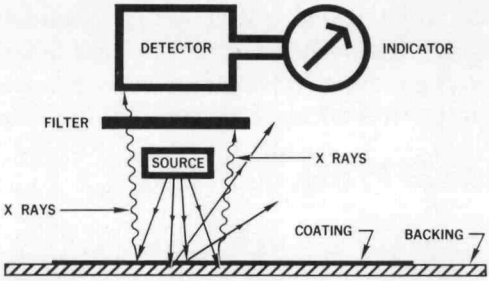



**Figure 13** *Principle of x-ray fluorescence.*

duced X rays are absorbed in the coating before reaching the detector, and so the intensity of X rays decreases with thickness. In both measurements a detector picks up intensity changes, and these are recorded as thickness values (Figure 14).

In both backscatter gauging and X-ray fluorescence, the detected radiation also depends on the density and atomic

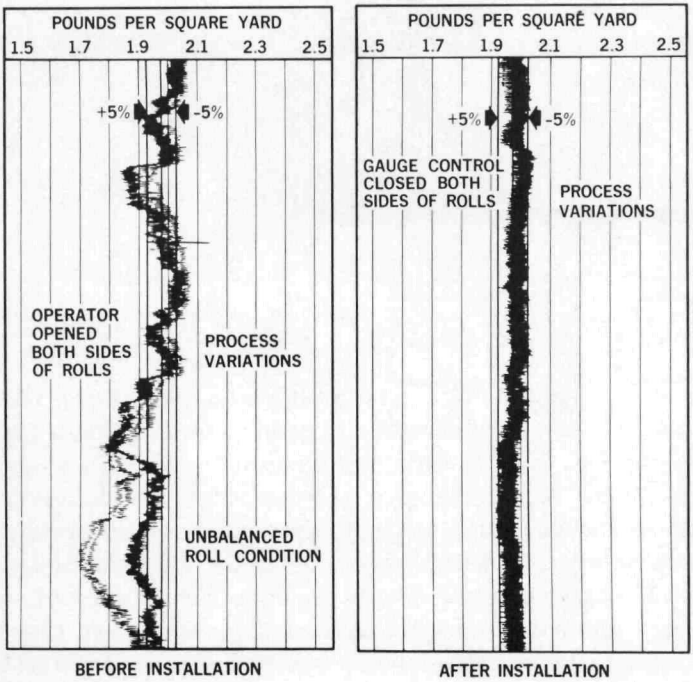



**Figure 14** *Results obtained at a tire plant by installation of radioisotopic thickness gauges. Thickness varied widely before installation but very little afterwards.*

number of the material being measured. Sometimes these qualities need to be determined in industry (Figure 15).

The chief advantage of backscatter gauging is that the thickness of an object can be measured if access is possi-

**Figure 15** *Measuring surface moisture of roadbed with a portable radioisotope gauge before paving.*

ble from one side only. An advantage of X-ray fluorescence is the extreme precision of its measurements (Figure 16).

Another type of gauge is the level indicator. This instrument "sees" the level of a substance in a container. It is used in the beverage industry, for example, to sort out at high speed partly filled cans (Figure 17). These gauges are also used in chemical plants to keep inventories of solutions of corrosive materials in tanks, in the coal industry to report which ore cars in the belly of a mine are full, and in many other industries.

Level gauges work on the "go-no-go" principle, like a light switch. When there is a substance between the source

Figure 16—DETERMINATION OF COATING THICKNESS BY X-RAY FLUORESCENCE SPECTROMETRY

| Material | Material activated | Precision |
|---|---|---|
| Platinum or gold on titanium | Titanium | Coating thickness of 2 to 50 millionths of an inch; accuracy of 1% |
| Iron-based ink on coated or uncoated paper | Iron | Ink thickness from 1 to 4 hundred-thousandths of an inch |

and detector, the indicator is "off"; when the material drops below the level of the source, it is "on". This gauge also is often used to control the rate of processes: By opening a remote valve when the indicator is "off", the gauge will change the inflow of materials to a container in which a processing operation occurs.

The simplest type of level gauge (Figure 18) has a radioactive source floating on top of the liquid or in a well surrounded by the liquid. A detector is moved up and down on the outside of the container until its maximum reading shows the level of the source.

When a source cannot be placed inside a container, source and detector can be mounted on opposite sides of the con-

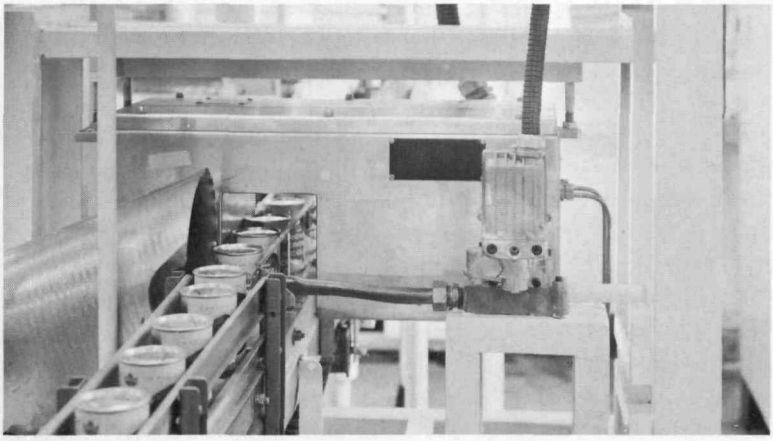


**Figure 17** *Detecting the level of liquid in cans of beverage. Improperly filled cans are ejected into the pipe at left.*

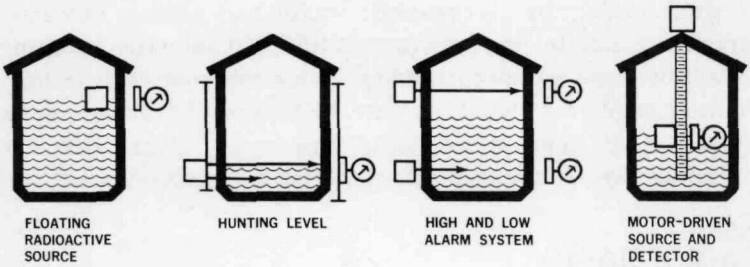



**Figure 18** *The principle of various types of level gauges.*

tainer and moved up and down together to hunt the level of the liquid. A sharp rise in radiation indicates that the rays are no longer passing through the liquid and that the surface level has been passed. Another type, the high-and-low-level alarm system, uses fixed detectors at the top and at the bottom of a tank.

More complicated devices use motor-driven servomechanisms that move the source and detector up and down the tank at the same level as the liquid.

## Pros, Cons, and Dollars

Radioisotope gauges have the same disadvantages as any other application of isotopes, plus a few more. The cost of the isotope is a negligible part of the total price of an installation. The meters, control equipment, and mechanical components may be complicated, delicate, and expensive. Despite these factors, radioisotope gauges are being used in more ways every year.

Radioisotope gauges require little power and maintenance, they can be placed deep in the heart of machinery (away from personnel), and they are economical. The radiation harms neither the materials nor its users in any way. In practice, gauges have proved so reliable that the AEC has relaxed some former requirements for testing them. In spite of the cost radioisotope gauges add to a manufacturing process, they save money. For example, some years ago about a hundred paper companies invested approximately $370,000 in radioisotope equipment and facilities. In one year, however, they realized a net saving of nearly $3 million. Thickness gauging accounted for 80%

of this saving by decreasing waste and saving raw materials. A single company saved $50,000 annually by using a radioisotope gauge to reduce scrap; the cost of switching to the gauge was $2200 a year.* Savings like these can be passed on to consumers either directly by lower prices or indirectly by providing products of better quality.

## RADIOGRAPHY

### Taking Pictures with Radiation

Radiography is a process of taking pictures with radiation other than normal light. A medical or dental X ray is an example. For the most part radiographs are made with X rays and gamma rays. The "pictures" are not really photographs but are shadowgraphs, much like ordinary shadows cast by objects in sunlight. But, whereas a shadow is formed when an opaque body prevents the transmission of all the visible part of sunlight, a shadowgraph results when a body prevents transmission of only part of the X rays or gamma rays.

X rays result when electrons bombard solid targets, such as copper. Gamma rays occur when some radioisotopes decay, as a result of changes in their atomic nuclei. They are not "produced", as you remember; they "just happen". Both X rays and gamma rays can pass through solid bodies, and their energies are an important consideration in comparing them. Examination of thick or dense specimens requires energetic (penetrating) radiations; examination of lighter metals, such as aluminum, requires far less energetic rays. And low-density objects, such as wood or plastics, can be radiographed with very "soft" rays.

The amount of radiation passing through a body depends on the penetrating power of the radiation and the mass (density–thickness relation) of the body. In other words, all materials are not equally transparent to radiation. A radiograph of an object made up of parts with different densi-

*Other examples of dollar benefits are given in a study published by the National Industrial Conference Board (see references, page 47).

ties or thicknesses would show differences, since the amount of radiation passing through it would vary from one part to the next (see Figure 19).

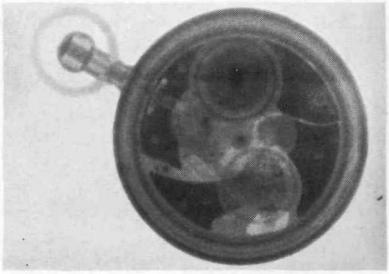


**Figure 19** *Radiograph of a pocket watch. The radiograph was made with promethium-147.*

In the last 20 years, gamma-ray sources for radiography have been widely used, mostly in the testing of welds. Early sources of gamma rays for "picture" taking were cobalt-60, iridium-192, and cesium-137. The use of gamma rays gradually has supplemented or replaced many traditional methods of testing materials, since, among all the testing methods known, none has the overall versatility of nondestructive gamma radiography.

## X Rays and Gamma Rays

Like X rays, gamma rays have a spread of energies, depending upon the radioisotopic source. An X-ray machine

Figure 20—RADIOISOTOPE CHARACTERISTICS

| Isotope | Half-life | Energy in Mev* |
|---|---|---|
| Iodine-125 | 64 days | 0.035 |
| Iridium-192 | 74 days | 0.2 (and several others) |
| Thulium-170 | 129 days | 0.084 |
| Gadolinium-153 | 236 days | 0.097 |
| Samarium-145 | 360 days | 0.06 |
| Iron-55 | 2.9 years | 0.006 |
| Cobalt-60 | 5.3 years | 1.33; 1.17 |
| Cesium-137 | 30 years | 0.66 |

*Mev is the abbreviation for million electron volts. One electron volt is the amount of kinetic energy gained by an electron when it is accelerated through a voltage difference of 1 volt.

can be adjusted by changing targets and voltage. With radioisotopes, adjustments are made by changing isotopes, and the range of energies is therefore much greater than in ordinary X-ray machines. Figure 20 lists common radioisotopes used in radiography and their characteristic half-lives and energies. You will note that the energies (really a measure of penetrability) vary over a broad range. This means that it is possible to maintain a stock of radioisotopes and to choose the one best suited to any problem at hand.

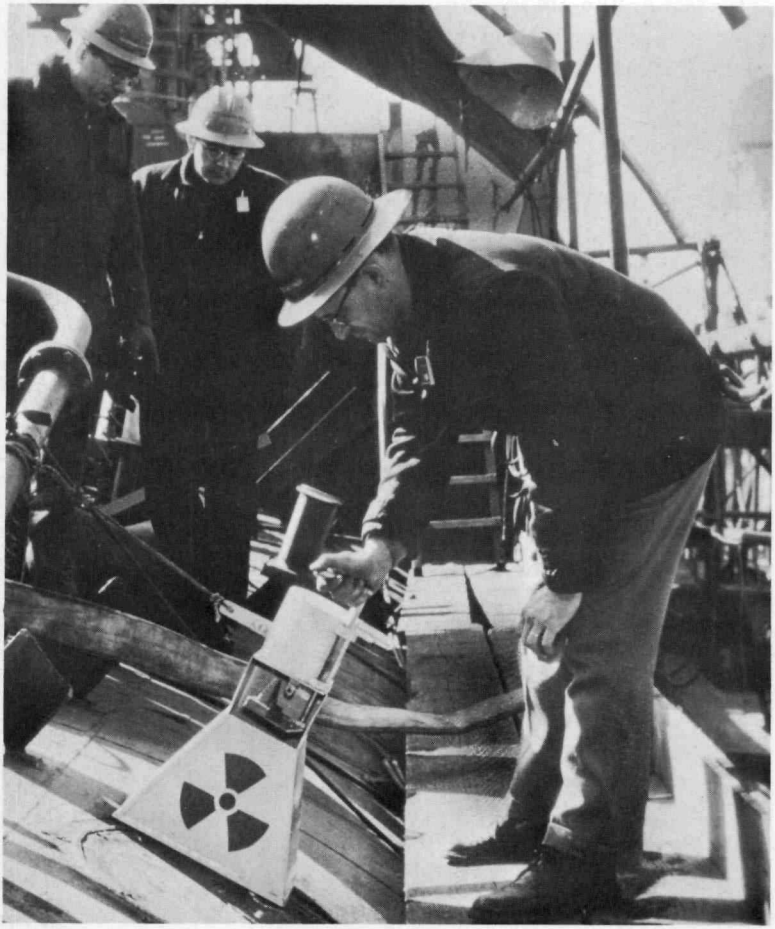


**Figure 21** *Using a portable radiation source for radiographic inspection of a submarine hull.*

## Sources, Equipment, and Applications

Many kinds of isotopic radiographic equipment are available. These include large fixed devices and small portable sources. Fixed devices are very similar to X-ray machines, but they require no electrical power, have no tubes to burn out, and in many cases last longer. Portable gamma-ray sources have the same properties as fixed sources, are not as heavy as battery-pack (portable) X-ray devices, and, of course, require no recharging (Figure 21).

"Point" sources—tiny "spots" of very concentrated isotopes—are important for some purposes, such as obtaining high definition in the examination of castings. They allow "inside-out" pictures, which are extremely difficult to make with X-ray machines. Samarium-145 and gadolinium-153 are two point-source isotopes used in a radiographic technique developed at General Motors Research Laboratories (Figure 22).

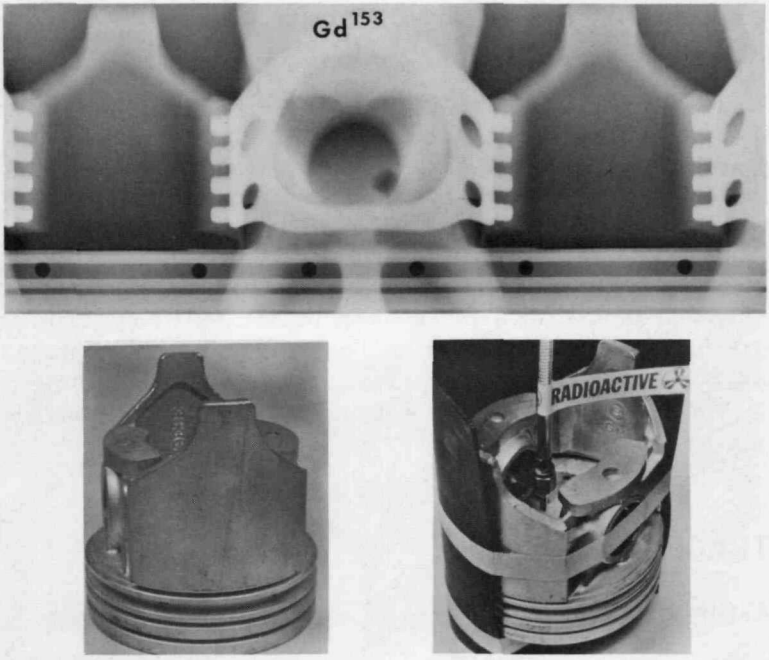



**Figure 22** *Above are aluminum pistons, shown in inside-out radiographs made with gadolinium-153. Below are the piston and the radioisotope source and film in place. Note tape holding film.*

## Autoradiography

Another radioisotope picture-taking technique is called autoradiography, or "self picture taking". Autoradiography combines tracer and radiographic methods; that is, radiation from a tracer is used to expose a photographic film. Suppose you want to know how the chemicals in an experimental fertilizer are distributed through a growing plant. You could add a radioisotope of phosphorus to the fertilizer and feed this to the plant. Then after a few days you could place leaves or roots of the plant on a sensitive photographic plate. The radioisotope that had been absorbed in the plant would expose portions of the film by its radiation. Similarly, metallurgical samples can be exposed to tritium gas and the specimens autoradiographed to give information about the effects of stretching, surface cracking, porosity, and other surface characteristics, because the gas collects in surface irregularities.

## Beta Radiography

It is also possible to use beta rays for radiography, somewhat in the manner that an electron microscope is used to take pictures, but without lenses and the other parts characteristic of a microscope. The technique is limited to examination of thin films and low-density materials.

## Advantages of Radioisotopes for Radiography

The principal advantages of radioisotopes, then, are (1) portability, (2) wide range of energies, (3) availability of point sources, allowing insertion inside cavities, (4) their unique usefulness for autoradiography, and (5) inexpensive use.

# TRACER USES

## A Gift of Lead

When the scientist George Hevesy was working with Ernest Rutherford, the famed English physicist, Rutherford received a gift of a large amount of lead from the only

uranium–radium mine then operating (located at Joachimsthal in Bohemia). The lead was valuable because it contained a radioactive material known as radium-D. We now know that radium-D is in fact a radioisotope of lead, but in those days it was known only as a disintegration product of radium. Rutherford was extremely anxious to get the radium-D for experiments, and he gave Hevesy the job of separating it from the lead. Hevesy worked for many months with all the ingenuity at his command but was never able to do it. In the end he was forced to conclude that these materials were "practically inseparable substances".

*George de Hevesy*

Hevesy decided to use the fact that the two substances were inseparable to study the behavior of lead. He went to Vienna in 1913 and worked with Frederick A. Paneth, an Austrian scientist, who had also been trying to separate radium-D from lead. The two used the tracer radium-D with stable lead to measure the solubility of lead sulfate and lead chromate in water. These salts are only slightly soluble, and this tracer method gave them the most accurate determination made up to that time.

During the next 10 years, Hevesy and his co-workers used natural radioisotopes as tracers in many studies of inorganic chemical reactions. In 1923 he used radium-D to trace the movement of lead in bean seedlings; this was the first use of radioisotopes in biological research. He was also the first to use stable (nonradioactive) isotopes as tracers (1934) and the first to use an artificial radioisotope, made in a cyclotron, in research (1935).

## Research on Piston Wear

Radioisotopes are important tools used in research to extend the life of our automobiles. The point of highest wear in any engine is where the piston ring rubs on the

cylinder wall. Small iron particles are worn off the piston rings and are carried away by the lubricating oil. The amount of this wear can be measured either by weighing the piston ring before and after running the engine or by measuring the iron that accumulates in the oil. Before the isotopic method was developed, an engineer had to run an engine for about 10 days to get a detectable weight change, even with the most sensitive balance. With radioactive tracers similar measurements can be made in a matter of minutes with results that are more reliable and at least 50 times as sensitive as those from weight tests.

Isotopic tracers were first used for the measurement of piston wear in 1947. The method makes use of the fact that extremely small amounts of radioactive isotopes in the particles abraded from the pistons can be detected and measured. There are several variations of the method. In one technique whole piston rings are put into a nuclear reactor and bombarded with neutrons to convert some of the iron atoms into radioactive iron. These rings are installed in an engine. The engine is run, and the oil is pumped through a detecting instrument to "count" the radiations from the radioactive iron particles that have worn off and accumulated in the oil.

Figure 23 shows how wear can be determined in a car under typical service conditions. Radioactive piston rings are put in the two front cylinders of the engine, and the oil is pumped through a counter where the amount of radioactive iron is recorded automatically. This method can also

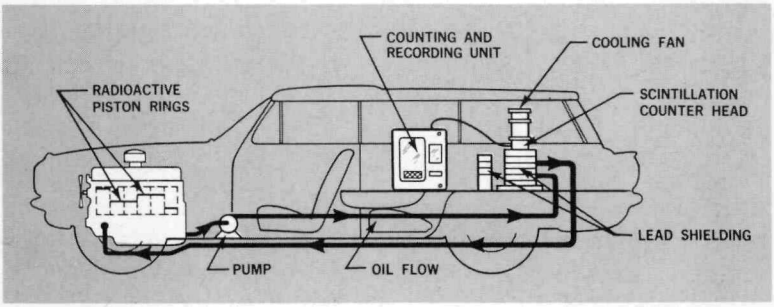



**Figure 23** *Car equipped for making engine-wear measurements with radioactive piston rings.*

be used in very large equipment, such as diesel engines for ships and locomotives (Figure 24).

Recently another sort of wear test has been developed. In this test workers run a nonradioactive engine and then measure the iron in a small sample of oil by the neutron activation analysis technique.*

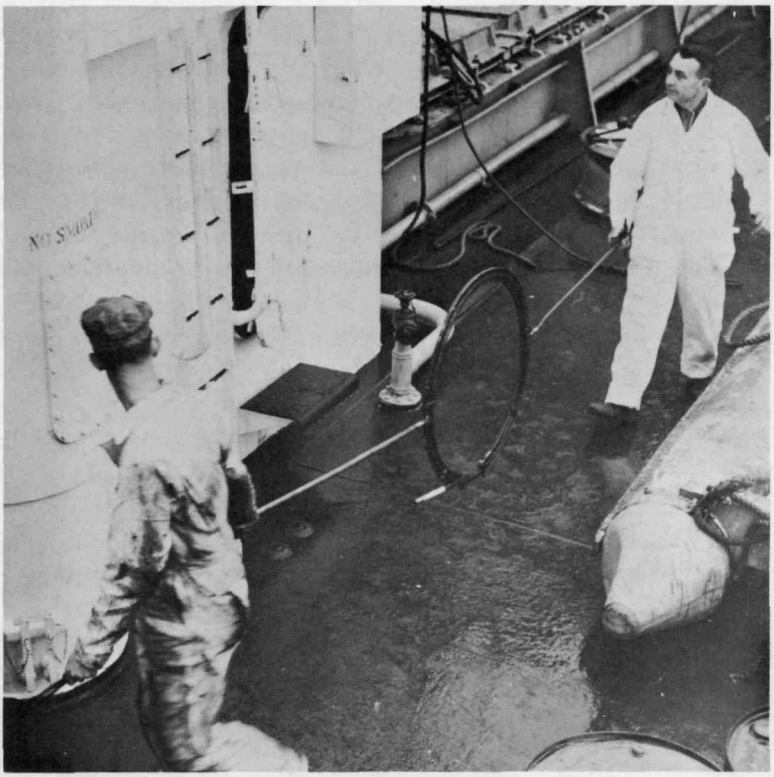


**Figure 24** *Radioactive 30-inch piston ring being installed in a large marine diesel engine.*

The saving from the use of radioactive isotopes in wear tests has been extremely large. For example, one firm spending about $3200 on each test found that it could obtain much better accuracy by using isotopes, which cost only $200. This company had been doing about 600 tests a year; so the saving was nearly $2 million annually.

*See *Neutron Activation Analysis*, another booklet in this series.

## Pro and Con

From the example just given, it is easy to pick out advantages of the tracer method:

1. The method is specific. The radioactive and stable iron atoms act chemically and physically in exactly the same way. Therefore, when a radioactive atom broadcasts a signal that it has moved from one place to another, it is a sure sign that its stable brothers have also moved.

2. The method is extremely sensitive. Running the engine for only a few minutes gives enough radioactive iron to be detected on a counter. In fact, it is possible to detect as little as $4 \times 10^{-17}$ (4 preceded by a decimal point and 17 zeros) of an ounce of radioactive iron-59. Because of this high sensitivity, a very small amount of a radioisotope will usually serve. This keeps costs low.

3. The method requires only simple equipment.

4. The method is usually nondestructive. In the engine example the change in the piston ring was detected without tearing the engine apart, and the effect of changes in operating conditions could be followed without having to "break in" the engine and rings after every test.

The accuracy of radioisotopic wear determinations is a little lower than that of other physical measurements, about 1 to 2 per cent, compared to an accuracy of tenths of a percent for "traditional" methods.

## From Oil Well to Gas Tank

Many industries use radioisotopes in a few operations, and a few use them in many operations. In the petroleum industry, for instance, isotopes are found everywhere—from the oil well to the gasoline storage tank. Let us take a little time to examine this industry, since it exemplifies so many aspects of radioisotope use.

In petroleum exploration one method of finding oil-bearing geologic formations is to lower radioactive needles into the ground or into test wells and measure the changes in their scattered radiation as they pass through various types of rock. A geologist makes a record, or log, of the amount of radiation at several places and draws a *profile*

**Figure 25** *Oil refinery at night.*

of the underlying layers of earth. This profile tells him whether there is justification for drilling in the area.

In the oil fields operators have found that they sometimes can put new life into an old oil well if they pour water into it. Radioisotopes are used to trace the oil and water and to tell whether there is enough oil to warrant bringing it to the surface by flooding.

At the refinery radioisotopes are used to follow the flow of material through various processes. Later, after the products (gasoline, light oils, motor oils) are separated by refining the crude oil, these may be tested with radioisotopes in the company laboratory. Information from these tests helps the company operate more efficiently.

Finally, oil is commonly shipped long distances through pipelines. Several companies often use the same pipeline, just as cattlemen use the same range for their herds. Cattle can be distinguished by their brands, but different oil batches ordinarily look alike. However, oil can also be "branded" by tagging the leading edge of each batch in the pipeline with a very small amount of radioisotope. Some of the isotope precedes company A's oil, for example, as it moves along, and another tracer is carried along ahead of company B's shipment. When the oil reaches the "corralling" area (in this case, a series of tanks at a distribution point), a man at a valve uses a radiation monitor to detect the radioisotope (Figure 26) and then routes A's oil into

**Figure 26**
*Typical Geiger-tube installation on exterior of pipeline.*

tank A and B's products into tank B. The routing also can be controlled by machine.

## Tracers in "Cat Crackers"

Crude petroleum is essentially a mixture of a number of materials, such as gasoline, kerosene, motor oils, and greases. In the early days of petroleum refining, enough gasoline could be obtained by simple distillation of crude petroleum. Today this process is inadequate. To supplement this, engineers found that heavier oils, much like those used in the crankcase of an automobile, can be broken down in a device known as a catalytic cracker (or "cat cracker") to make more gasoline.

A cat cracker consists of three parts: a reactor, a stripper, and a regenerator (Figure 27). The petroleum oil and a powdery catalyst, usually a silica–alumina mixture with a large surface area, are mixed together in the reactor at about 900°F; the petroleum breaks down into gasoline, and into coke and heavy oils, which are deposited on the catalyst. The catalyst carrying the coke and oil then goes to the stripper section, where high-temperature steam removes the oil, and thence to a regenerator, where air is blown through at about 1100°F to burn off the coke and oil.

These crackers are gigantic pieces of equipment. One unit may hold 900 tons of the catalyst and stand as much as 200 feet high. The regenerator, which is the largest part of the equipment, is usually 30 to 40 feet in diameter.

To make a cracker work at its highest efficiency, engineers must know how the catalyst is moving through each section. Radioisotopes are effective for this determination. Usually a gamma-ray-emitting isotope, such as scandium-46, is added to the catalyst. Then a small amount of this radioactive-tracer-tagged catalyst is admitted to the reactor, and from samples taken at various points in the stripper and regenerator it is possible to tell quickly how fast the catalyst moves from one vessel to the next. Engineers can thus locate places in any of the three vessels where the catalyst is not mixing with the other materials and can remedy the situation by appropriate changes, such as in-

creasing the gas flow. One company reports saving almost $200,000 in research costs by using radioisotopes to study catalyst mixing.

The catalyst surface slowly becomes inactive so that it no longer does its job. Therefore each day some catalyst

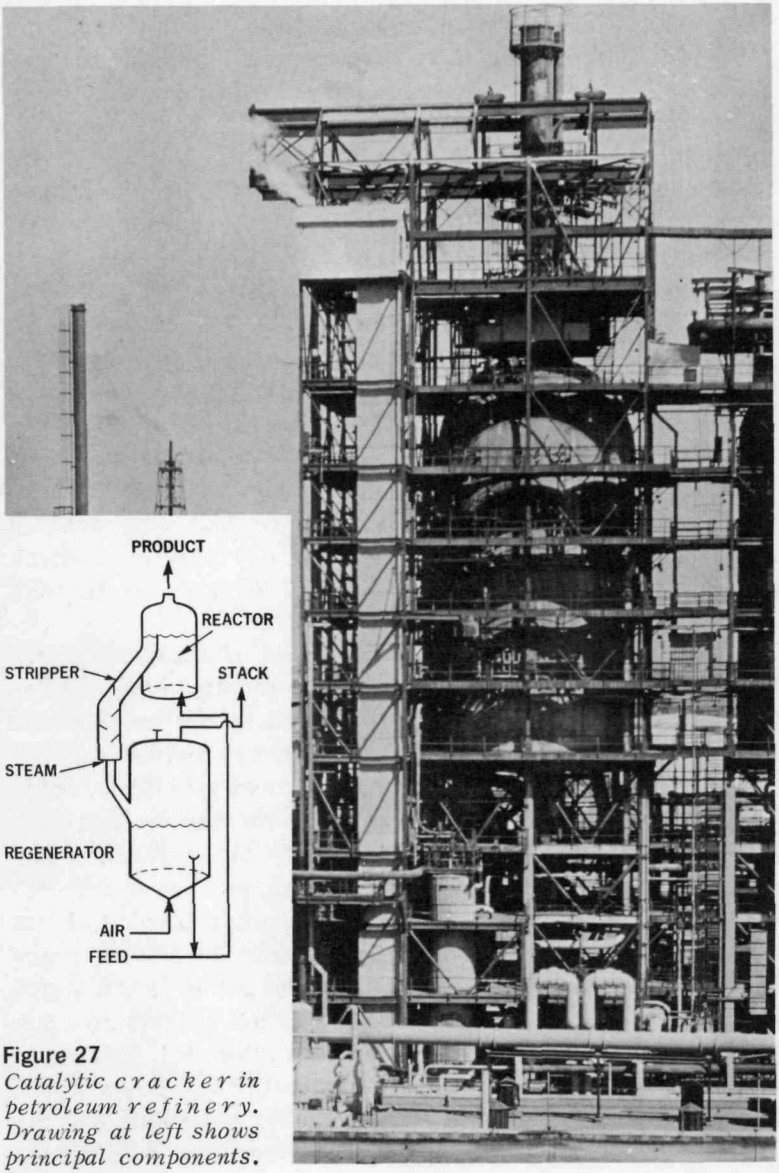



**Figure 27**
*Catalytic cracker in petroleum refinery. Drawing at left shows principal components.*

must be removed from the system and be replaced with fresh. With radioactive tracers engineers can determine how much catalyst should be removed and how much fresh catalyst should be added.

Air rushes through a refinery regenerator at the rate of 90,000 cubic feet a minute. (This is about the amount of air that would be contained in a three-story-high tank having the floor area of a tennis court.) This blast blows 5 to 10 tons of the finely powdered catalyst out the stack every day. In one study with tracers, these losses were measured exactly, and the flow of air into the regenerator was regulated to give the most efficient balance between regeneration and loss of the catalyst. One refinery reported saving $240,000 annually in catalyst losses by using tracers.

The tracer-method sensitivity is so great that, if 1 millicurie of a gamma-ray emitter (about 1/100,000 oz. of commonly used isotopes) is mixed with 500 tons of catalyst, the radioactivity can be easily detected in a quart of the mixture. This amount of radioactivity does not endanger workers in the refinery. A person would have to breathe in, or eat, several tons of tagged catalyst to be harmed by its radioactivity.

## Isotope Dilution

Many biologically important substances, such as vitamins, hormones, and enzymes, are very complex organic chemical molecules or mixtures. Workers in the pharmaceutical industry have done extensive research to find out how much of a vitamin, for example, is found in various food substances. In the past, the only way to find out was to assess the effect of the vitamin on animals. For example, if an animal is fed a diet containing no vitamin $B_{12}$, it will develop anemia, a deficiency disease; if it is then fed a vitamin $B_{12}$ preparation, it will get well. The amount of $B_{12}$ in the preparation may be estimated by observing how rapidly the animal recovers. This assay method is obviously tedious, expensive, and not very precise.

With radioactive tracers, complex substances can be analyzed by the process known as isotope dilution. An analysis of the amount of vitamin $B_{12}$ in a sample of mixed vi-

tamins may be made in the following manner:

1. Prepare a pure sample of vitamin $B_{12}$ containing radioactive cobalt as a tracer. Determine the amount of radioactivity in a given weight of the sample.

2. Add the radioactive tracer-tagged $B_{12}$ to a known amount of the vitamin mixture that you want to analyze.

3. Mix tracer and vitamins thoroughly.

4. Take a sample of the mixture.

5. Separate a small amount of the vitamin $B_{12}$ from the mixture and purify it.

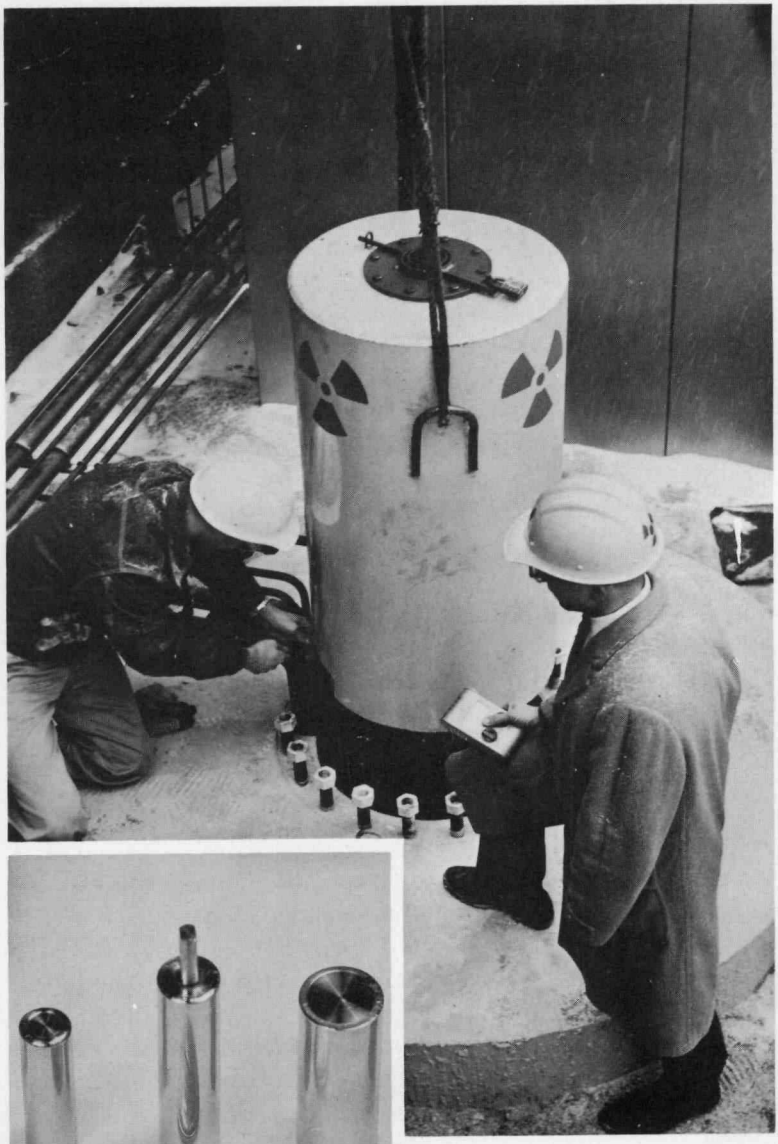
6. Determine the weight of this new sample and its radioactivity. The activity of the new sample of vitamin $B_{12}$ per unit of weight will not be as high as that of the original sample because it has been diluted with the vitamin $B_{12}$ in the mixture. You can then calculate how much vitamin $B_{12}$ must have been in the original mixture to cause the change in the amount of the radioactivity of the tracer.

This procedure is exceedingly simple compared with the one using experimental animals. One food manufacturer estimated that he saved $500,000 a year by using the isotope-dilution method to assay the vitamin $B_{12}$ in his food products.

## Soap, Solvents, and Missiles

Companies that make soap or detergents are interested in how effectively their products will remove dirt from soiled clothes. Although it has been difficult to make radioactive "dirt" for testing that is as good as the real dirt normally found on clothes, some fairly good substitutes have been developed. Radioactive "dirt" is washed from clothes with new soap products, and the dirty water is examined with instruments to measure the amount of radioisotope removed.

One of the dangers in missile and rocket operations is the possibility of accidentally contaminating liquid oxygen (LOX) with grease, dirt, or residual fuel before mixing it with the new fuel in the ignition chamber. This contamination may cause premature ignition; even the slightest trace of fuel in the oxygen lines can cause an explosion. One missile manufacturer tagged his usual fuel with a radio-



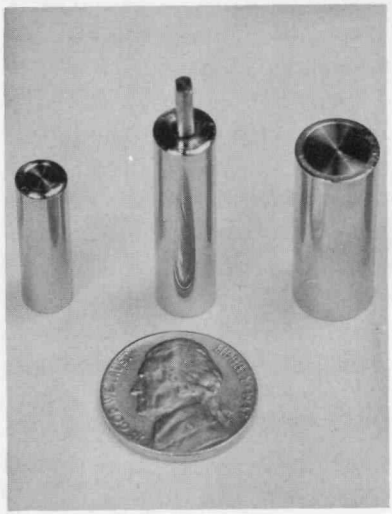


**Figure 28** *Large and small radioactive sources. Above is a cobalt-60 source for a chemical firm's ethyl bromide process. Below are several sources for specialized irradiation purposes.*

isotope, and the oxygen lines were deliberately contaminated with it. Then various cleaning compounds were used in the system. Any fuel remaining in the lines was revealed by its radioactivity. The manufacturer was surprised and delighted to find that a $2-per-gallon solvent was more effective than a $5-per-gallon product he had been using. Substitution of the cheaper solvent resulted in a saving of $600,000 a year.

## RADIATION PROCESSING

By far the largest quantity of radioisotopes used in industry is in the preparation of radioactive sources for radiation processing. Radiation from these sources is used for various purposes, such as catalyzing chemical reactions, sterilizing medical supplies, and preserving food. The weight of a radioisotope used in a processing source may be about two pounds, compared to a fraction of an ounce used in a radiography source (Figure 28). (The amount used to trace oil through a pipeline is too small to be weighed on any scale.) The radioisotope most used for large-scale processing is cobalt-60.

In some industries chemicals, heat, pressure, or a catalyst may be used to bring about chemical reactions and to change raw materials into useful products. Some manufacturers have found that chemical reactions can be made to occur more cheaply with the aid of radiation and that sometimes the changes so induced are better than those made in other ways. Of course, the amount of radiation, like the amount of heat or chemicals, must be regulated.

When radiation strikes a mixture of chemicals, small molecules may combine to make larger units, or molecules that are already large may be bent or even broken.

The Dow Chemical Company is now using gamma radiation to make ethyl bromide, an important chemical used in the manufacture of drugs. Two simple gases, ethylene and hydrogen bromide, are mixed in a large tank. In the center of the tank is a cobalt-60 source. Its radiation makes the two gases combine to form a liquid, which is taken out of the container through a pipe. Not only is the new process

more economical than a former method, but the ethyl bromide it produces is purer.

The Esso Research and Engineering Company has installed a radiation source for making detergents that can be destroyed by bacteria so that waste suds will not clog sewers, waterworks, and rivers. Chemists are studying ways of producing other chemicals with radiation, including hydrazine, a rocket fuel.

Methods of modifying the properties of textiles by irradiation are being developed. Wool, a very complex molecule, is improved by small amounts of radiation. When cotton, another very complex molecule, is joined to a simple organic chemical by radiation, an improvement of the fibers results.

Polyethylene, a good plastic for packaging, is often wrapped around food and shrunk into place with heat. Ordinary polyethylene is too weak to be handled this way. If it is treated with just the right amount of radiation, however, some of the molecules break and combine with others to make the plastic strong. A spoon made from irradiated plastic does not become misshapen in hot water (Figure 29).

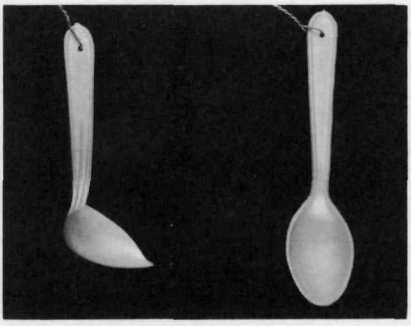


**Figure 29** *Effect of radiation on thermal stability of plastic utensils.*

Wood may be made harder and therefore more useful by soaking it in a simple chemical and irradiating the soaked piece so that the chemical molecules combine between the wood fibers to make a plastic. The beauty of the wood is unchanged.

Radioisotope power sources are used for satellites and navigation beacons.*

*See *Power from Radioisotopes*, another booklet in this series.

In the food industry radiation may be used in three ways: (1) to prevent sprouting of root crops, such as potatoes, (2) to eliminate insects from grain before storage, and (3) to pasteurize food, that is, to kill most, but not all, microorganisms on it.* Some food processors are irradiating bacon so that it may be kept for a long time without refrigeration. Usually food processing takes the form of pasteurization; that is, it is exposed to enough radiation to prevent spoilage for weeks or months but is not completely sterilized, since this might tend to change the flavor.

Complete sterilization is needed, however, for hospital supplies and companies in the United States, England, and Australia sterilize hypodermic syringes, pharmaceuticals and surgical sutures by irradiation. The radiation does not destroy the protective wrappers on the sutures as moist-heat sterilization sometimes does.

In an Australian plant, goat hair is irradiated to destroy the harmful anthrax bacterium before the hair is sold for making cloth or rugs.

## THE ISOTOPE BUSINESS

At the time that Rutherford and Hevesy were using natural radioisotopes or even when man-made isotopes became available from the first cyclotron, radioisotopes couldn't "turn a dollar" because they were scarce and expensive to make. All the naturally radioactive radium ever refined amounts to only about 3 pounds. By contrast, a large nuclear reactor now produces more radiation each year than would be emitted by 100 tons of radium.

Today there is a growing isotope business, although not all isotopes are money-makers (and some probably never will be) because of the nature of radioisotopes and the economics of their production and distribution.

After World War II, in June 1946, radioisotopes first became available from Oak Ridge National Laboratory,

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*See *Food Preservation by Irradiation*, another booklet in this series.

Oak Ridge, Tennessee, which was the only producer. There were 86 users that year. Within 10 years 90,000 shipments (containing about 212,000 curies of radioactivity valued at $11 million) were made to 4000 users. By 1964 there were about 8000 users of radioisotopes licensed by the Atomic Energy Commission; one-third of these users were in industry. An annual gain of 15% from an estimated $17 million worth of radioisotopes sold in 1963 was expected by many to continue through the 1960s. U. S. sales of radioisotope-labeled pharmaceuticals alone amounted to more than $5 million in 1964.

In other countries the national governments still own and control isotope production, sales, and use. The trend in the United States is toward private ownership, and control by states. Each year finds new impetus coming from industry for production and use of isotopes, and the federal government has encouraged this trend. For example, the AEC recently transferred production of six isotopes to private industry. Production of nine more isotopes is also in private hands, which brings the private sales to almost $2 million a year.

## WHAT THE FUTURE HOLDS

Isotopes are such versatile substances that all their industrial applications could not possibly be covered in this booklet. (For example, isotopes are being used more and more by the paper, textile, and plastics industries to eliminate static electricity. Another extensive use is in luminescent signs.)

As our economy expands—stimulated by automation, advanced technology, and space exploration—the uses of isotopes are expected to multiply. Keeping in mind that the future defies prediction, we venture to cite several industrial areas in which use of isotopes may be expected to increase.

◀ **Figure 30** *Radioisotopes in storage area at the AEC's Oak Ridge National Laboratory in Tennessee. Note remote control tongs for handling containers of various shapes and sizes (center).*

## Gauging

As one of the earliest applications of isotopes, gauging has had more time to develop than most other techniques. Researchers today seek to improve gauge sensitivity, reliability, and precision. It is fair to expect industries now using gauges to apply these advanced machines and techniques to refine their processes. Companies not presently using gauges probably will adopt them. Perhaps radioisotope density gauges to test earth fills will be as common at the site of new buildings as bulldozers are today.

## Radioisotope Tracers

Radioisotope tracers should have an important place in the manufacture of transistors and semiconductors, which function because of extremely small amounts of impurities that have been added to very pure materials. As purer materials and more exacting methods are used, sensitive techniques, such as isotopic tracing and the related method of activation analysis, will be required for process and quality control.

An exotic use for radioisotopic tracers has been proposed to help determine whether there are living organisms on Mars. Project Gulliver space scientists propose an unmanned device that will land on Mars, shoot out a string covered with silicone grease, and then pull it back. The retrieved string, covered with Martian soil, will be soaked in a culture broth containing radioactive carbon. If bacterial life is present in the soil, radioactive carbon dioxide gas will be given off and automatically measured by a radiation counter. From the counting rate sent to Earth by radio, scientists will be able to tell whether there is life on Mars and, if so, something about the kind of life.

## Radiography

As more isotopes become commercially available, more tailor-made radiographic sources can be provided. These will give users a variety of radiations from which to choose and will allow radiographs of everything from watermarks in paper to slight imperfections in metal castings. Better

point sources can be made, which will permit better photographs in less time.

## Radiation Processing

Radiation processing will undoubtedly use the largest amounts of radioisotopes. Producers of chemicals may use radiation to make old chemicals better and cheaper and to make new chemicals. Textile manufacturers may be able to incorporate desirable properties into natural and synthetic fibers right at the mill.

Many more foods may be successfully preserved by radiation processing.

In hospitals the autoclave, now used to sterilize surgical instruments, may become a thing of the past.

Indeed, the future of radioisotopes looks bright. The extent of tomorrow's use will reflect the success of today's development.

# APPENDIX I — RADIOISOTOPE APPLICATIONS IN INDUSTRY

## Flow-Rate, Transport, and Distribution-pattern Measurement

1. Measuring the amount of mine seepage, industrial waste, and effluent flowing into rivers, lakes, and oceans
2. Measuring the flow of solid dispersions
3. Studying the flow of glass lubricant in the hot extrusion of stainless steel
4. Measuring the transport rate of sponge iron flowing from a continuous ore-reduction unit
5. Measuring flow rates in various petroleum refining and processing operations
6. Determining the rate of exhaust gas discharged from an automobile
7. Analyzing the flow of gas through an air-filter system
8. Studying the economics of pneumatic and hydraulic conveying of fine coal
9. Studying sand movement on swimming beaches
10. Determining the movement and distribution of "mud" in sugar thickeners

## Leak Detection

1. Determining the location of leaks in oil-well casings
2. Testing the tightness of an abandoned slate quarry to be used for temporary oil storage
3. Locating freon leaks in refrigerator coils
4. Testing possible leakage between cross streams in a heat exchanger
5. Studying the characteristics of leaks through engine seals

## Wear Study

1. Measuring the wear of rollers in engine-gear boxes on farm machinery
2. Determining the life of switches in automobile backup lights
3. Measuring the erosion wear of water on turbine blades in a hydroelectric plant
4. Evaluating the influence of various molding compounds on the wear of steel molds used in forming plastic radio and television cabinets
5. Determining the wear resistance of various kinds of floor waxes
6. Studying contact wear of distributor points
7. Measuring piston-ring wear in refrigerator compressors
8. Studying corrosion wear in gas-fired thermoelectric generators

## Isotope Dilution Analysis

1. Determining sulfur content of petroleum liquids after desulfurizing
2. Routinely assaying for vitamin $B_{12}$ and vitamin D during drug manufacture
3. Determining phosphorus content of steel during open-hearth production
4. Continuously measuring acid-olefin ratios in alcohol production
5. Determining sulfate concentrations in chromium plating solutions
6. Measuring the solubility of wax in milk and orange juice

## Applications in Research and Development

### USES DERIVED FROM FOUR CHARACTERISTICS OF THE TRACER TECHNIQUE

#### Ability to Label Certain Atoms

1. Investigating the flow of aluminum during extrusion
2. Locating materials pumped into oil and gas wells
3. Determining the efficiency of industrial mixers
4. Studying the distribution of an embrittling impurity in metal and alloy production

#### Detection of Minute Quantities

5. Measuring the washing efficiency of detergents
6. Determining the vapor pressure of strontium oxide
7. Following the migration of mercury in fluorescent lamps
8. Detecting dye contamination in multicolored textile printing machines

#### Nondestructive Location of Material

9. Determining carbon dioxide absorption on vacuum tube sections
10. Studying the bonding of metal skin to the honeycomb framework of airplane wing sections
11. Measuring the buildup of combustion residues inside an engine
12. Determining the fit of flush rivets by labeling penetrating oil

#### Detection of Inaccessible Material

13. Locating a stuck carrier in a pneumatic message-tube system
14. Measuring piston-ring rotation during engine operation
15. Identifying carry-over of crank-case oil from air compressor into air lines
16. Determining residence time of wood chips in a pulp digester

## Applications in Activation Analysis

1. Determining the amount of impurities, such as manganese, nickel, and copper in ultra-high-purity silicon
2. Measuring the amount of iridium in steel
3. Determining the retention of selenium in glass to which it had been added as a decolorizer
4. Determining inhomogeneities in forgings and castings
5. Measuring the presence of toxic concentrations of beryllium dust
6. Investigating the structure of failed components of rotating machinery

## Applications Employing Autoradiography

1. Studying the distribution of carbon impurities in zirconium and zirconium-base alloys
2. Measuring the absorption of ions from water solutions on the surface of metals
3. Investigating the mobility of carbon in steels under the influence of electric currents
4. Determining the effect of passivating agents such as chromates, phosphates, and oil additives on the corrosion of metals
5. Studying the effect of vulcanization on sulfur distribution in synthetic rubber
6. Locating inclusions and grain boundary segregation in metals

## Products Gauged With Radioisotopes

### THICKNESS GAUGES

adhesive tape
aluminum strip
asbestos
asphalt shingles
battery separators
brass plate
cellulose acetate
coated abrasives
corrugating medium
cotton webbing
floor coverings
galvanized zinc
glass fabric and yarn
paper
- asbestos paper
- book paper
- cigarette paper
- felt-backed paper
- laminated paper
- masking paper
- paperboard
- reinforced waterproof paper
- resin-impregnated paper
- roofing paper
- sandpaper
- wax paper

plastic
polyethylene film
pressure-sensitive adhesive
roofing felt
rubber
- rubber-coated fabric
- rubber-cushion sponge
- rubber-insulated tape
- rubber thread

shipping container liners
soda-cracker dough
solder
stainless steel
strip steel
surgical adhesive
tin-plated steel
tire fabric
titanium
vinyl wall coverings

### DENSITY GAUGES

cement slurries
condensed milk
fat in baby food
foam rubber latex
gasoline
ground corn
hydrochloric acid
jet-engine fuel
liquid fish extracts
meat content of noodle soup
milk of lime
mineral content of ore slurries
plastic resins
pulverized coal
sodium hydroxide
starch
sugar solutions
sulfuric acid
synthetic rubber
tobacco in cigarettes

### HEIGHT OR LEVEL GAUGES

bauxite ore
caustic soda
chemicals of many types
coke and coal
detergents
gasoline
grain syrups
liquid polymers
molten aluminum
molten glass
molten scrap iron
paper pulp slurries
petroleum
wood chips

## Tracer Applications in the Chemical and Rubber Industries

1. Absorption of silicones in emulsifiers in hand creams
2. Acid–olefin ratio in alcohol production
3. Adsorption of fluorine on teeth
4. Application of finishes on synthetic fibers and films
5. Availability of iron chelates to growing plants
6. Contamination of food-processing equipment by cleansing agents
7. Diffusion of sulfur and zinc into rubber compounds during vulcanization
8. Effectiveness of oil removal from steel rails
9. Fate of catalyst fragments from redox catalyst reactions
10. Fate of inhibitors and terminators in polymerization
11. Fate of toxic residues from feed additives in milk
12. Interaction of detergent components and fabrics
13. Interaction of flotation agents and minerals
14. Kinetics of exchange reactions of halogens and halogenated methanes
15. Mechanism of drying lacquers
16. Metabolism of drying agent used on potatoes and onions
17. Metabolism of emulsifiers used in ice cream cartons
18. Migration of antimony in lead-storage battery grids
19. Purification of semiconductor materials
20. Sulfur content of petroleum liquids after desulfurizing

## Applications in Metallurgy

1. Investigating role of hydrogen in metals as it applies to defects in porcelain enamels
2. Studying mechanism of corrosion inhibitors
3. Determining moisture content of oxide films
4. Investigating interaction of various metals and alloys with materials of refractory construction
5. Studying mechanism of passivation of iron by chromates
6. Determining sulfur content and extent of migration in steel
7. Measuring sodium diffusion in pot lining of electrolytic cells
8. Studying dendrite formation
9. Determining mode of action and efficiency of scavengers
10. Investigating effect of hydrogen sulfide on steel corrosion
11. Studying the diffusion of carbon in steel alloys and nickel in aluminum–nickel alloys
12. Studying the kinetics of slag metal reactions
13. Determining the origin of nonmetallic occlusions in steel

These typical or representative examples were compiled from the book *Radioactive Isotopes in New York State Industry,* published by the New York State Office of Atomic Development, September 1963.

# APPENDIX II — PRINCIPAL INDUSTRIAL PRODUCTS AND ACTIVITIES USING RADIOISOTOPES*

| | Number of firms |
|---|---|
| Instruments and related products | 48 |
| Consultation and research | 39 |
| Chemicals and chemical products | 30 |
| Pulp, paper, and paper products | 21 |
| Primary metals and fabricated metal products | 19 |
| Electrical and nonelectrical machinery | 14 |
| Transportation equipment | 13 |
| Petroleum and coal products | 8 |
| Pharmaceutical and cosmetic products | 6 |
| Food and kindred products | 5 |
| Plastic and glass products | 5 |
| Rubber products | 3 |
| Other (includes companies licensed to process isotopes for resale) | 39 |

*In New York state.

# SUGGESTED REFERENCES

## General

*Radioisotopes in the Service of Man,* Fernand Lot, United Nations Educational, Scientific and Cultural Organizations, available from UNESCO Publication Center, New York, 1958, 82 pp., $1.00. This booklet, written for the general reader, describes worldwide applications of isotopes.

*Radiation: A Tool for Industry,* Arthur D. Little, Inc., Cambridge, Massachusetts, 1959, 392 pp., $5.50. This book summarizes world technology in radiation uses.

*Radioisotopes for Industry,* Robert S. Rochlin and Warner W. Schultz, Reinhold Publishing Corporation, New York, 1959, 190 pp., $4.75. The purpose of this small book is to show the value of isotope methods. It assumes no prior knowledge of radioactivity or nuclear science.

*Radioisotopes in Industry,* John J. McMahon and Arnold Berman, Studies in Business Policy No. 93, National Industrial Conference Board, Inc., New York, 1959, 136 pp., $2.75. A survey of more than 650 companies using radioisotopes is reported.

*Isotopes in Action,* Dorothy Harper, The Macmillan Company, New York, 1963, 172 pp., $2.95. A non-technical description of uses of isotopes in industry, science, medicine, and agriculture.

*Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy,* Volume 19, *The Use of Isotopes: Industrial Use,* United Nations Publications, New York, 1958, 366 pp., $12.50.

*Radioisotopes in Science and Industry: A Special Report of the U. S. Atomic Energy Commission* (January 1960), available from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 20402, 176 pp., $1.25. This report covers the milestones, status, and use of radioisotopes in science as well as in industry.

## Some Specific Applications

Nucleonics, G. W. Leddicotte. *Analytical Chemistry,* 36: 419R (April 1964). A review of fundamental developments in nucleonic applications in analytical chemistry.

Radiation Makes Better, Longer Lasting Tires. C. H. Stockman, D. J. Harmon, and H. F. Neff, *Nucleonics,* 15: 94 (November 1957).

Graft Copolymers—A New Technology?, D. J. Metz, *Nucleonics,* 16: 73 (April 1958).

Tracing Catalysts in Refinery Crackers, V. P. Guinn, *Nucleonics,* 14: 68 (May 1958).

## Motion Pictures

Available for loan without charge from the AEC Headquarters Film Library, Division of Public Information, U. S. Atomic Energy Commission, Washington, D. C., 20545, and from other AEC film libraries.

*Industrial Applications of Radioisotopes,* 57 minutes, sound, color, 1960. Produced for the AEC by the Army Pictorial Center. This semitechnical film, for high school and college-level audiences, describes the principles and techniques for gauging industrial thicknesses, densities, and levels; radiography; and radioisotope tracing.

*Opportunity Unlimited: Friendly Atoms in Industry,* 28½ minutes, sound, color, 1962. Produced for the AEC by the Army Pictorial Center. This film surveys the widespread use of radioisotopes by industry to make better products—from ships to nylon hose—with more efficiency and an impressive record of safety.

*Gauging Thickness With Radioisotopes,* 4½ minutes, sound, black and white, 1958. Produced by George Tressel Productions. This technical film, for high school and college-level audiences, shows briefly how beta gauges are used for precise measurement and control of feed-back apparatus in steel, plastic, rubber, and paper manufacturing.

*Radioisotopes: Safe Servants of Industry,* 28 minutes, sound, color, 1963. Produced for the AEC's Division of Isotope Development of Molesworth Associates and Orleans Film Productions. This film surveys the widespread uses of radioisotopes in industry with emphasis on safety.

"The Magic of the Atom" series of nontechnical films, 12½ minutes each, sound, black and white. Produced by the Handel Film Corporation. These films are suitable for intermediate- through college-level audiences.

*Tagging the Atom,* 1954. This film describes the use of radioisotope "tracers" as scientific research tools and shows details of radioisotope production, methods of handling, purification, and packaging.

*The Industrial Atom,* 1956. This film shows the use of radioisotopes for detecting hidden leaks, for locating stuck scrapers in oil pipelines, and for studying piston-ring wear to test the quality of lubricating oils.

These films in the series entitled "The Radioisotope" are available from the First U. S. Army, Audio-Visual Communication Center, Fort Jay, Governors Island, New York, 10004, and from other Army Audio-Visual Communication Centers. All are in black and white and have sound.

*Fundamentals of Radioactivity* (PMF 5145A), 59 minutes, 1951.

*Properties of Radiation* (PMF 5145B), 68 minutes, 1952.

*Practical Procedures of Measurement* (PMF 5145C), 48 minutes, 1951.

*Methodology* (PMF 5145D), 40 minutes, 1951.

*The Physical Principles of Radiological Safety* (PMF 5145E), 51 minutes, 1954.

*The Practice of Radiological Safety* (PMF 5145F), 33 minutes, 1952.

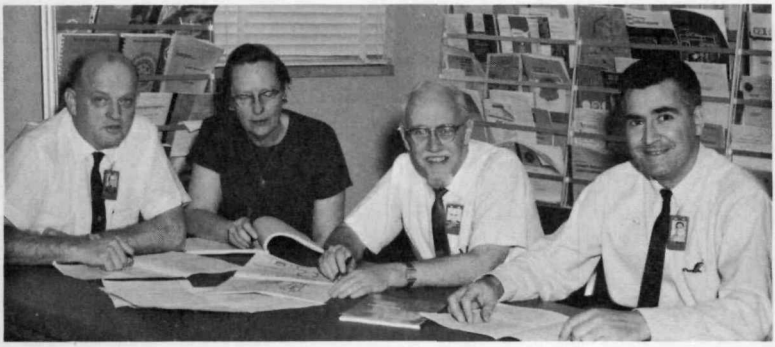
*Radioisotopes in Agricultural Research* (PMF 5147B), 41 minutes, 1952.

*General Sciences* (PMF 5147C), 46 minutes, 1952.

## THE COVER

Use of radiographic equipment, employing the radioisotope, cobalt-60, is shown in the cover photograph. A technician is testing the large valve for flaws in the metal. Radiography accounts for one of the largest uses of radioisotopes in industry.

## THE AUTHORS



Staff of the Isotopes Information Center at Oak Ridge National Laboratory, Oak Ridge, Tenn., in conference as they prepared this booklet. Left to right they are the Director, Dr. P. S. Baker, Martha W. Gerrard, Dr. Robert H. Lafferty, Jr., and Domenic A. Fuccillo, Jr. Dr. Baker, the senior author, is also Assistant Superintendent of the Isotopes Development Center. Mrs. Gerrard has had wide experience as a technical editor, including supervision of the proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy held at Geneva in 1958. Dr. Lafferty is an analytical chemist and a veteran science administrator. Mr. Fuccillo is an editor of the technical progress review "Isotopes and Radiation Technology". Among them they have had 53 years experience on the Laboratory staff.

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Tables in Appendixes I and II courtesy New York State Office of Atomic Development.

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