RADIOISOTOPES

A New Tool For Industry

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by

SIDNEY JEFFERSON, B.Sc., A.C.G.I.

Leader of the Technological Irradiation Group, Isotope Division, Harwell

With a foreword by

DR. HENRY SELIGMAN

Head of the Isotope Division, A.E.R.E. Harwell

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FOREWORD

THE progress of industrial applications of radioisotopes during the last few years has been spectacular. There is hardly an industry where radioactive materials are not used either for research or process control. For the layman it is, however, very difficult to follow this rapid development, and I welcome the appearance of this book just at the present stage of progress.

The author has addressed himself foremost to businessmen and people with technical responsibilities, and also to all those who would like to keep in touch with the rapid progress of this expanding field of using radioisotopes in novel and money-saving ways. The reader will find, for example, that some entirely new techniques have been developed which eliminate all the well-known difficulties. It is gratifying to see that the author has made the whole field clearly understandable, which is surely the result of his practical experience in this work.

The great importance to industry of these new tools can best be illuminated by quoting figures which have been published in the United States. There it has been estimated that already 100 million dollars are saved annually by employing radioactivity for the benefit of industry.

I have no doubt that this book will find a wide circle of interested readers in all professions.

H. SELIGMAN

PREFACE

I HAVE been encouraged to write this book by the appreciation shown by many people who have consulted the Isotope Advisory Seıvice at Harwell. On so many occasions, it has come as a surprise that the use of radioactive isotopes is so straightforward and free from serious complications, that I felt the practical details of the subject should be made available to a wider public.

The first part of this book is largely an account of work with which I have been concerned in the last few years, and examples have been selected to help in explaining the broad principles. The second part deals with the elementary characteristics of radioactive isotopes and their radiations.

I should like to record my thanks to the many colleagues at Harwell who have given me valuable help and advice in my work. I also wish to thank Sir John Cockcroft, the Director of the Atomic Energy Research Establishment for permission to publish this book.

ABINGDON. S. JEFFERSON

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INTRODUCTION

RADIOACTIVITY has a history as long as that of the universe itself, but its existence was hardly suspected until recent times. It remained undiscovered because the radiations could be neither seen nor felt. Their discovery had first to wait until photographic film existed, and then until some film was accidentally exposed to the radiations. Once the radiations were discovered, other ways of detecting radioactivity were soon developed.

The principal radiations from radioactive substances are alpha particles, beta particles and gamma rays. Alpha particles are the cores of helium atoms. Another way of describing them is to say that they are positively charged helium atoms. Beta particles are simply electrons. They are called beta particles to indicate that they have come from radioactive material. Gamma rays are similar in nature to X-rays, light rays and radio waves. Some radioactive substances radiate or emit beta particles only, while others emit beta particles and gamma rays. Still another group emits alpha particles as well as the beta particles and gamma rays.

Alpha and Beta Particles

Some of the radiations can be stopped by the thinnest tissue paper, and others can penetrate 10 in. of steel. Alpha particles have most difficulty in penetrating matter, whether it is solid, liquid or gaseous. Alpha particles, which are slow, are said to have low energy, and are more easily stopped than fast or high-energy particles. In fact, alpha particles continue to exist only as long as they move fast enough to avoid collecting electrons. The addition of two electrons to an alpha particle cancels its positive charges, and so turns it into a normal helium atom. Beta particles, being repelled by other electrons, are better fitted for penetrating matter (see Fig. 1). There is, however, an overlap in the penetrating power of alpha and beta particles, the faster alpha particles being more penetrating than the slower beta particles.

Gamma Rays

Gamma rays are different from the alpha and beta particles, not only in penetrating power but also in their very nature. The two types of particle, although small, have weights which can be found by indirect measurements, whereas gamma rays are like X-rays and light rays, and have no substance. For this reason it is not strictly correct to speak of alpha rays or beta rays.

Effective Life and Half-life

It will be shown in later chapters that before employing radioactivity, the type and energy of radiation with the degree of penetration to suit a particular purpose must be decided upon. Having made a choice, a radioactive substance which continues to emit the desired type of radiation for a suitable length of time must be found. The effective life of radioactive materials ranges between millionths of a second and thousands of years. In every case, the radioactivity falls to a half in a characteristic time which is called the *half-life*. After another half-life the activity becomes halved again, i.e. it will be reduced to a quarter, and after a further half-life the activity will fall to one-eighth of the original strength. The effective life of a radioactive material is usually up to three or four half-lives, depending on the application.

The half-life of a given radioactive substance is always the same, and is unaffected, for all practical purposes, by temperature, pressure, magnetic or electric fields or by mechanical vibration of any kind. This independence of local conditions is particularly useful in industrial applications, where the maintenance of a steady temperature or pressure would be difficult.

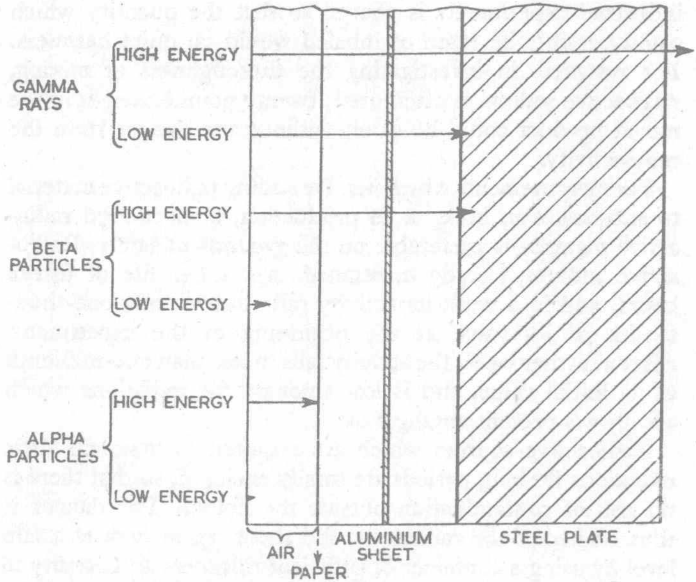

FIG. 1.—COMPARISON OF THE PENETRATION OF ALPHA PARTICLES, BETA PARTICLES AND GAMMA RAYS THROUGH AIR, PAPER, ALUMINIUM SHEET AND STEEL PLATE

Safe Levels of Radiation

There is no danger in using radioactive materials provided that some very simple precautions are taken. The safe level of radiation which can be allowed on the human body is well established, and methods of using radioactive material can usually be devised to keep well below the maximum permissible level—or 1 *M.P.L.*, as it is called. In addition to avoiding high external radiation, it is important to prevent dangerous radioactive materials from entering the body. In particular, eating food contaminated with radioactivity, breathing contaminated dust or air or allowing radioactive material to enter the blood-stream through open cuts or scratches should be avoided. The radioactive material used in industrial experiments is chosen so that the quantity which could possibly be eaten or inhaled would be quite harmless. For instance, in investigating the thoroughness of mixing, radioactive sodium is often used; twenty pounds weight of the mixed product could be eaten without any danger from the radioactivity.

For measurements which involve adding radioactive material to substances in bulk, or in production, a short-lived radioactive material is preferable on the grounds of safety. Radioactive sodium, already mentioned, has a half-life of fifteen hours, and in a week its activity falls to less than one-thousandth of its value at the beginning of the experiment. After a further week, the activity falls to less than one-millionth of its initial value, and is lost amongst the radiations which are always present amongst us.

Radioactive sources which are required to maintain their radiations for long periods are totally enclosed, so that there is no risk of contamination outside the holder. The danger is thus limited to the radiations, and these can be kept at a safe level by using a container of sufficient thickness and density to cut down the radiations, except in the desired direction.

Almost everyone using radioactivity for the first time experiences a sensation of adventure which is artificially increased by its remote association with atomic bombs. With experience, there comes a growing respect for the versatility of this new tool in solving problems in industrial research and production.

Part I

INDUSTRIAL APPLICATIONS

CHAPTER ONE

RADIOACTIVE MARKERS

ON the rare occasions that a radium source is lost at a hospital, the news of the ensuing search is often published in the daily press. The loss of a radium source is a serious matter for two reasons—first, because the radium is very costly, and second, because it is especially dangerous if not kept inside a sealed container. It takes 1,600 years for radium to decay to half strength, so there is a high probability that the capsule protecting the source will become damaged or broken long before the radioactivity has fallen to a safe level. However, a radium source radiates high-energy gamma rays and, fortunately, these can be detected through several feet of earth or concrete by using special apparatus. It is these penetrating rays which sometimes reveal the presence of the radium in such unlikely places as slag-heaps or even down a sewer.

Geiger Counters

A Geiger counter connected to a portable ratemeter, (shown in Fig. 2) is one of the detectors used to find a lost radium source. As soon as the Geiger counter comes within a few feet of the radium source and is triggered by some of the gamma rays, it passes short impulses of electric current which are fed to the portable ratemeter, where a pointer instrument indicates the rate of arrival of the impulses from the counter. The impulses can also be heard as clicks on earphones connected to the ratemeter, and the first sign of the radium source is a noticeable increase in the frequency of the clicks. It may be possible to complete the search using the earphones, but if there is any doubt as to whether the Geiger counter is getting closer or farther away from the radium source, the pointer instrument on the ratemeter will give a more definite indication than the clicks.

The ease with which buried or otherwise inaccessible objects can be found has given rise to a wide variety of applications of radioactivity. Some radioactive material emitting high-energy gamma rays must be attached to the objects which are to be traced at a later stage. Fortunately, the radioactive material can be used in such small quantities that there is no serious increase in the size or weight of the labelled objects.

Examples of Radioactive Marking

The following examples of marking have been chosen to demonstrate the strength of radioactivity needed in typical applications.

The first example involves such a weak source that it can be handled safely without any shielding. Pneumatic-tube delivery systems are used by financial houses for transporting valuable documents from office to office. This method of transportation is particularly attractive on account of the saving in time and the security in transit. Since there is always a slight chance of one of the documents becoming jammed and lost in the pneumatic ducting, some rapid means of finding it is most desirable. The documents are enclosed in carrier boxes for transit, and if a small radioactive source is attached to each carrier it can be easily located by means of a Geiger counter on the outside of the ducting.

Radioactive cobalt is a suitable material for this purpose, because it emits energetic gamma rays and has a half-life of more than five years. The strength of source for each carrier should be about 15 microcuries, which does not require any special shielding. A strength of 15 microcuries means 15

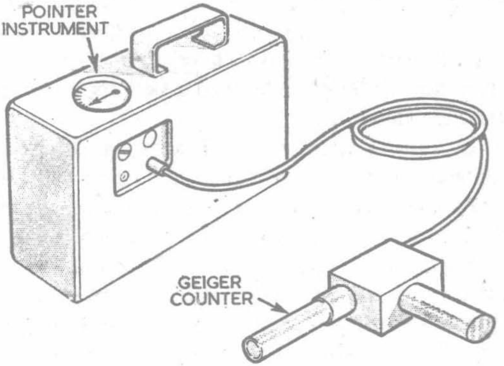

FIG. 2.—
GEIGER COUNTER
AND PORTABLE
RATEMETER

millionths of a *curie*—the latter being the recognised unit of radioactivity. The *millicurie* is an intermediate unit equal to 1,000 microcuries. In each microcurie of radioactive material, 2·2 million atoms emit radiations every minute!

If a large number of the tube-delivery carriers labelled with radioactive sources are stored together, the gamma dose rate in the vicinity may be too high. If the dose rate is above the safe level, there are two possible remedies. A screen of some dense material can be placed between the radioactive sources and the nearest operator, or the distance between the sources and the operator can be increased. The latter is usually the more convenient, because doubling the distance reduces the intensity of the gamma rays to a quarter. To cut down the gamma rays from cobalt 60 to the same extent, a screen of lead 1 in. thick is needed.

The next application is a means of finding objects which have been buried 2 or 3 ft. deep in the ground for several years. It is common practice to protect underground pipelines from corrosion by placing a series of metallic electrodes in the ground some distance away. It is difficult to install a durable marker for these electrodes without interfering with the cultivation of the land. If radioactive sources of about 10 millicuries of radioactive cobalt are initially attached to the electrodes, they can be found by a Geiger counter held a few inches above the ground. The electrodes with the radioactive markers can be buried to a depth of 2 or 3 ft., at which depth they are unlikely to be disturbed by a plough or any other farming machine.

In this application no health hazard arises between the installation of the electrode and its renewal after a period of years. At both these times, the radioactivity of a single source is low enough for handling tongs to be adequate to keep the operator at a safe distance. If a number of 10-millicurie sources are to be transported, then it is usually necessary to house them in a screening pot or box to cut down the gamma rays. Before calculating the thickness of screening required, it is necessary to decide on the permissible level of gamma-ray flux at some specified distance from the sources.

A useful rule of thumb is that it is safe to work 1 ft. away from a millicurie of radioactive cobalt (cobalt 60) for 40 hours each week. If the source strength is increased from 1 to 80 millicuries, then the safe time at 1 ft. distance is reduced to $\frac{40}{80}$ hours, i.e. half an hour. There are many instances where this period of half an hour per week need not be exceeded, and so shielding is unnecessary.

If the time of carrying 80 millicuries of cobalt 60, held at a distance of 1 ft., is likely to be one hour per week, then the shielding should reduce the gamma-ray flux to one half. This reduction is achieved by putting the 80 millicuries of radioactive cobalt in a lead pot with walls and lid of $\frac{1}{2}$ in. thickness. If the carrying time is likely to be increased to 2 hours (i.e. doubled), then the gamma-ray flux must be halved again. This calls for another $\frac{1}{2}$ in. of lead, making the total thickness up to 1 in.

Half-thickness

The thickness of screening material which reduces radiations to half strength is sometimes called the halving thickness. The *halving thickness*, or *half-thickness* as it is more commonly called, depends on the energy and type of radiation. A pair of

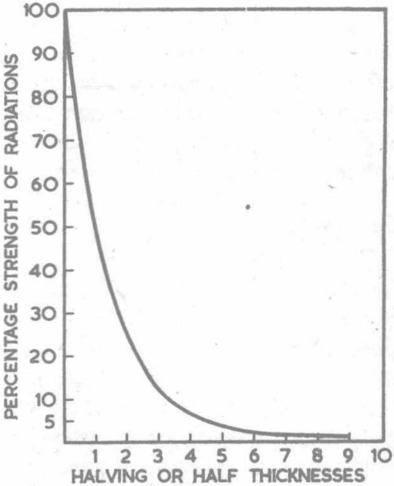

FIG. 3(*a*).—EFFECT OF SUCCESSIVE HALVING THICKNESSES OF ABSORBER ON THE STRENGTH OF RADIATIONS ON A LINEAR SCALE

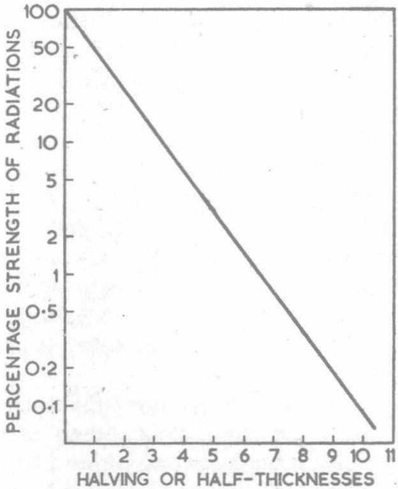

FIG. 3(*b*).—EFFECT OF SUCCESSIVE HALVING THICKNESSES OF ABSORBER ON THE STRENGTH OF RADIATIONS ON A LOGARITHMIC SCALE

charts indicating the effect of successive halving thicknesses are shown in Figs. 3(*a*) and 3(*b*). In Fig. 3(*a*) the scale of radiation intensity is linear, i.e. each unit is represented by the same distance on the scale. In Fig. 3(*b*) the scale of radiation intensity is logarithmic, i.e. each reduction of intensity by a given factor is represented by the same distance on the scale. A reduction by a factor of one thousand is difficult to read on Fig. 3(*a*), but it is clearly shown to result from less than 10 halving thicknesses on Fig. 3(*b*).

Go-devils

The next example calls for even stronger radioactive sources for marking go-devils, which are used to clean out pipelines. Since the function of the go-devil is to scour the line and to push the debris along, it is not surprising that a blockage is a frequent occurrence. A typical go-devil is shown in Fig. 4. It is forced along the pipeline by water or oil, which is pumped in at high pressure. In the past, listening methods have been used to locate go-devils jammed in the line, but great skill is required and even experts can be mistaken in interpreting the variety of curious noises which can be heard on a pipeline.

If a source of 200 millicuries of cobalt 60 is attached to a go-devil, it can be detected through about 4 ft. of earth. Thus, if the track of the pipeline is marked out on the ground, the progress of the go-devil can be followed by using a Geiger counter. This method of following is unnecessarily laborious because the go-devil makes an unmistakable noise when it passes uncovered sections of line at valve pits. The progress of the go-devil can thus be checked by listening at the valve pits; failure of the go-devil to arrive at a pit indicates a hold-up in the previous section. Valves are usually spaced at three-mile intervals along a pipeline, and so this is the longest length of pipeline in which a go-devil need be sought.

The search is carried out by walking slowly along the track of the pipeline with a sensitive detector held close to the ground. If the track of the pipeline is not known to within 1 ft., then a radio-frequency "mains finder" should be carried by a second operator to define the track of the pipeline more accurately. When the go-devil is found and all attempts to move it have failed, it must be cut out of the pipeline.

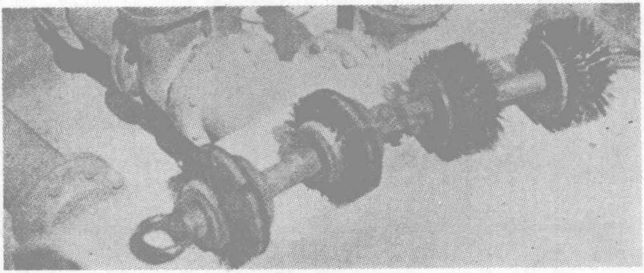

FIG. 4.—A TYPICAL GO-DEVIL

The wire bristles clean the walls of the pipe through which the go-devil is driven by hydraulic pressure.

When the pipeline has been uncovered, the exact position of the radioactive source can be found to within 1 in., because the gamma rays are no longer absorbed by the earth and, if necessary, the detector can be taken nearer to the pipe. Before cutting the pipe, the positions of the front and back of the go-devil can be worked out quite accurately from a knowledge of the position of the source on the go-devil. The total length of a go-devil is sometimes 3 or 4 ft., and if its position is uncertain, there is a strong probability of wasteful excavation and cutting. The earlier listening methods might not give an exact position because the predominant noise could come from either end of the go-devil.

Fitting a 200-millicurie Source

The fitting and removal of a 200-millicurie source must be undertaken with some care. This is especially true when the go-devil becomes stuck and the pipe has to be cut and manipulated in a narrow trench which does not allow the men concerned to keep more than a foot or two away from the source. It will be remembered that the tolerable level of gamma rays from a 1-millicurie source occurs at 1 ft. away from the source. With a 200-millicurie source, the gamma flux is 200 times the

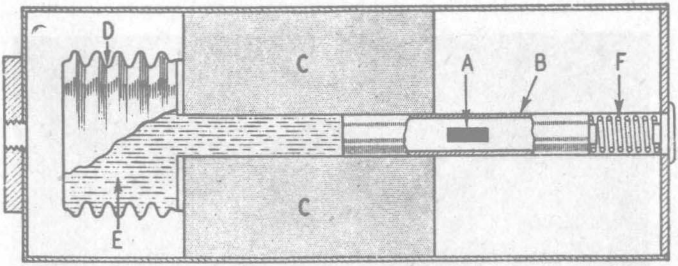

FIG. 5.—PRESSURE-OPERATED SHIELD FOR COBALT 60 SOURCE USED IN GO-DEVIL OPERATION

(*Patent application No.* 29196/54)

flux from a 1-millicurie source. To overcome the difficulties of working with a high-activity source attached to a go-devil, the arrangement shown diagrammatically in Fig. 5 has been devised. The cobalt source *A* is mounted in a cylinder *B* which is normally situated in the centre of the shielding block of lead *C*. If the local pressure increases, as it does in the pipeline, the metal bellows *D* tend to collapse, and so the oil filling *E* forces the source *A* in its cylinder *B* along the tube out of the lead shielding. The spring *F* is chosen so that the source is shielded at atmospheric pressure, which is the condition while fitting the go-devil and removing it from the pipeline.

At any other time when it is desirable to shield the source, the pressure in the pipe can be reduced and then the source will return to its shielding box. This device reduces the difficulty of cutting out a high-activity source from a pipe which is lying in a narrow trench. The pressure must be low before the pipeline is cut, and so the source is safely shielded while any of the workers are near to it.