

# APPLICATION OF RADIOISOTOPES TO SUGAR FACTORY CONTROL

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## Abstract

The principles and scope of the application of radioisotopes and ionising radiation in industry are reviewed as an introduction to nuclear methods of control in sugar milling and refining. Details of the South African usage of radioactive materials are given, indicating the absence of the sugar industry. The potential of the radiotracer technique is emphasised in the light of reported investigations.

## Introduction

The use of radioisotopes as tracers is well established in South African agriculture (Marais<sup>6</sup>) and has also been applied to sugar cane agronomy (Wood and Wood<sup>11</sup>). However, although the penetrating radiations from radioactive sources are widely used by other industrial concerns for measurement of density, thickness, level, etc. (Table I), no radionuclide has been put to active use in any South African sugar factory. (The source installed at the Transvaalse Suikerkorporasie, Malelane, as level controller in the De Smet plant, was never commissioned.) Consequently, this paper is intended to introduce gauging with radioactive sources to sugar milling and refining, as well as to indicate possible uses of radioactive tracers to solve problems in process control.

## Principles of Application

The applications of radionuclides depend on the characteristic property of radioactivity, namely, the emission of ionising radiation by the unstable atomic nuclei, as explained in the Appendix. These rays can be detected with great sensitivity by modern electronic apparatus and can be measured quantitatively. Such applications are particularly versatile, both in the range of application as well as in the techniques which can be used (Erwall, Forsberg and Ljunggren<sup>3</sup>; Gregory<sup>5</sup>). The latter can be classified in accordance with three general principles:

1. The ease and precision with which ionising radiations and, hence, the presence of the radioisotope can be determined.
2. The changes brought about by the absorption of ionising radiations in matter.
3. The effect (absorption, scattering) which an irradiated material exercises on the intensity and nature of the radiation.

### 1. Tracing

Radioactive materials can be located and measured by detection of their radiations. The radiation rate is proportional to the number of radioactive atoms present (i.e. the mass), but independent of pressure, temperature, chemical composition, etc. The type and energy of the radiation identify the

radionuclide and thus the element of which it is an isotope.

The natural activity (uranium, thorium, potassium, tritium, etc.) of the material concerned or the activity caused by irradiation with neutrons, etc., or the addition of radioactive material can be used as tracer. The first is limited by the low availability and weak activity of natural radioactive materials; neutron activation produces a uniform radioactivity right through the sample, provided that it is small enough and that it yields a suitable radioisotope—this is also a very sensitive analytical method, which can determine most elements qualitatively and quantitatively; the last-named method offers the possibility of labelling the object or material which is to be traced by its physical addition or incorporation into a chemical compound. Suitable radioisotopes exist for almost all the chemical elements—less suitable isotopes in the case of hydrogen, carbon, nitrogen, oxygen, aluminium, etc.

The sensitivity of detection is dependent on the nature and energy of the radiation but can be almost 100% for rays which reach the sensitive volume of the detector. Depending on the specific activity,  $10^{-6}$  to  $10^{-12}$  gram of an element can be determined. The activities required for most tracer experiments can also be limited so that no particular radiation hazard exists for the radiation worker. This is especially the case when a nuclide with a short half-life is used, which loses its activity fast enough for the end product to be sufficiently inactive for human consumption; this requires a local source of isotope production.

### 2. Radiation Effect

The energetic nuclear radiations can knock the orbital electrons from the atoms of the irradiated material with resulting changes in chemical bonds. Molecules are partly broken up and from the fragments new compounds may arise. No specific chemical products are, however, obtained because the radiation effects are random and not concentrated on specific electrons. In addition, the amount of radiation, even with very large doses, is only a small proportion of the number of molecules in the irradiated material\*.

Thus, the ionising effect of nuclear radiation can only be used when it is not individual molecules which are influenced, but biological cells (sterilisation, pasteurisation, mutation), or when a synthetic reaction is initiated by a small amount of the compound formed (vulcanisation) or by a chain reaction (polymerisation).

\*Even the high dose (10 million rads), necessary for sterilisation, produces only one ionisation per thousand molecules of water.

Lower radiation doses can, however, be usefully employed to eliminate static electricity or to initiate gas discharges. In addition, the luminous effect of radiation on a fluorescent material is generally used, e.g. in watches and other dials.

### 3. Influence of Material on Radiation

When nuclear radiation penetrates material the intensity change is, at first approximation, dependent only on the amount of material in its path. The simplest application is to determine whether a container (cigarette, acid tank, molten metal ladle, etc.) is full or empty.

When quantitative measurements of thickness or density are made, the choice of radiation is, however, more important. For the control of thin paper or aluminium foil beta rays are used; radiography of several inches of steel is possible if a source of penetrating (high energy) gamma rays is employed.

The scattering of radiation also serves as a measure of the amount of material present. Gamma rays are used to determine the wall thickness of pipes from the outside. In the same way the thickness of a coating of material on a denser backing can be established by beta scattering.

Radiation is, however, also used to analyse material qualitatively as well as quantitatively. By means of radiation the characteristic X-rays of the particular element are generated, which can then be determined selectively. The use of a radioisotope source provides a simpler and cheaper method than conventional X-ray fluorimetry.

All the above radiation analyses are non-destructive and yield no radioactivation products. They, therefore, lend themselves to automation of the production machine concerned.

### Gauging

As the measurement and control of level, density, weight, etc., play such an important part in the sugar factory, the theory and application of radioisotope gauges will be considered in greater detail. Such measurements can be performed in production plants directly through the walls of the pipe or container by means of a gamma source and a suitable detector for measuring the variation in absorption owing to the change in the amount of material interposed.

The measurement of level or height is the easiest type of gauging and, for the control of one or two level limits, simple Geiger counter instruments, together with radioactive point sources suffice to operate a relay, when a sudden change of absorption occurs at the point because the level limit is exceeded. An accuracy of 1 mm is attainable with a time of response from 1 to 30 seconds.

A continuous, proportional regulation of levels requires a quantitative indication of radiation intensity linear to the level height. This indication can be obtained by means of a vertically fixed rod-shaped source, the length of which corresponds to the measuring range. Depending on the level of the filler material a varying quantity of radiation will strike the measuring counter. Control over a height of up to 3 metres is possible with an extended  $^{137}\text{Cs}$  or  $^{60}\text{Co}$  source and, using a scintillation counter, an

accuracy of  $\pm 1\%$  may be obtained with a response time of 25 seconds.

As described by Trost<sup>10</sup>, nuclear level gauges have been adopted largely in those cases where older methods utilising floats and probing gauges fail. Radioisotope methods transcend the difficulties of measuring height levels of corrosive or highly viscous liquids, materials at high pressures or temperatures, and solid and molten materials.

The measurement of density (or thickness or weight) is critical in a great number of industrial processes. Although density may be of interest in itself, it is often more important as a measure of composition or of concentration of solids in suspension. Density measurement by the nuclear method is based on the principle that absorption of gamma (or beta) radiation increases with the mass of material.

If a suitable radioactive source and radiation detector are mounted on opposite sides of the material, the amount of radiation reaching the detector is given by

$$N = N_0 e^{-\mu m}$$

where  $N_0$  is the count without any material,  $\mu$  the mass absorption coefficient and  $m$  the mass per unit area (gram per  $\text{cm}^2$ ).

The variation of  $\mu$  with atomic number is small for beta particles and high energy (above 300 keV) electromagnetic radiation, but low energy gamma rays are absorbed preferentially in high atomic number materials. Thus the property of the material measured by the transmission of beta particles or high energy gamma rays is  $m$ , the mass per unit area. When the thickness is constant, as for liquids or slurries in a pipe, the density can be measured; hence, the detector can be calibrated in terms of thickness or density. Preferential absorption of low energy radiation from special sources is used to determine impurities of higher atomic number in a material of lower atomic number, such as the sulphur or lead content of hydrocarbons.

The error in measuring thickness or density with radioisotope sources has been calculated by Dietzch<sup>2</sup>, and the most suitable radiation characteristics for any given gauging problem have been determined by Platzek and Meyer<sup>7</sup>. For a fixed source strength it is found that the error in measuring  $m$  is minimum when  $\mu m = 2$ , but, as the minimum is broad, values of  $\mu m$  from 0.3 to 3 are acceptable in practice—as indicated in Table II. The accuracy obtained with a measuring time of a few seconds is usually of the order of 1%, between 0.1% and 5%.

The method is non-destructive and no contact is required with the material being measured. Furthermore, such measurement is independent of the temperature, pressure, viscosity and chemical properties of the material. As the sources are completely sealed, contamination and ingestion of the radioactive material are practically impossible. The radiation dose is reduced below the recommended maximum permissible level by appropriate shielding. Furthermore, maintenance requirements are virtually negligible.

Instruments are commercially available for the continuous measurement, registration and control of the density of liquids, opaque matter, slurries, bulk goods and sinter materials with an accuracy of up to  $2 \times 10^{-4}$  g/cm<sup>3</sup>. In a sugar solution the measuring accuracy obtainable is  $\pm 0.1\%$  of sugar.

The use of the above-mentioned nuclear gauges can be further extended by electronic methods for the automatic control of industrial processes. In many cases such instruments considerably facilitate automation of production and enable it to be raised to a level previously unattainable. In the book by Shumilovskii and Mel'tser<sup>9</sup>, a sound theoretical basis is given for the use of radioisotopes in instrumentation and control. It is important to note that the cost of the radioactive source and detector comprises only a relatively small fraction of the total price of a nuclear gauge, which may include sophisticated control circuitry; existing electronic instrumentation will usually require only small modification to allow for the signal from the radiation detector instead of from the conventional sensor.

#### Use of Radioisotopes in South Africa

According to the Atomic Energy Act No. 90 of 1967 (previously No. 35 of 1948) all radioactive materials in South Africa are under the statutory control of the Atomic Energy Board. Such control is exercised with the minimum of regulations, promulgated in Government Gazette No. R510 of 5th April, 1963 (modified version in near future), but with emphasis on the appointment of well-qualified inspecting physicists, who also act in an advisory capacity.

When applying for an authorisation, the prospective institution is required to nominate a responsible person (with alternate), suitably qualified to assume responsibility for the safe handling of the particular radioactive material. Furthermore, appropriate facilities and monitoring instruments are required as well as regular medical surveillance and personnel monitoring. However, in the case of sealed sources used in installed gauges, exemption can usually be obtained from many of the regulatory requirements, as the associated radiation hazard is usually negligible after installation, on condition that regular leak tests are carried out on the source to prevent any possible contamination.

An efficient, country-wide Radiation Protection Service, with film badges, is operated by the Bureau of Standards. At the end of 1967 there was a total of 197 institutions with authorisation by the Atomic Energy Board to use radioactive material for non-medical purposes; of these, 141 were industrial firms, mostly making use of sealed sources, as indicated in Table I. The associated control was effected so efficiently that the average dose (as indicated by film badges) received by the 1,586 radioactive radiation workers (3,898, including X-ray users) in 1966, was only 0.12 rems, i.e. 2.4% of the permissible 5 rems per year.

Since the first importation on 27th July, 1948, the number of consignments from abroad has grown to 1,244 batches of 55 different radionuclides im-

ported during 1967—used predominantly for medical purposes. In the meantime, the high flux reactor, SAFARI-1, of the Atomic Energy Board, went critical on 18th March, 1965, making possible the local production of all neutron-produced radionuclides: 107 batches of 14 different nuclides were produced in 1967 for users outside Pelindaba. Complemented by the CSIR cyclotron in Pretoria, which has been exporting special, accelerator-produced nuclides on an international scale, any radionuclide can now be produced in South Africa—although not necessarily on a commercial basis.

In addition to its regulatory responsibility the Atomic Energy Board is also concerned with the promotion of isotope applications. Several training courses, conferences and symposia have already been organised under its auspices, while at Pelindaba it has an Isotopes and Radiation Division which, inter alia, specialises in radioisotope investigations.

#### Applications in the Sugar Industry

Level and density gauging with radioactive sources are well-established in South African industry and suitable instruments can be obtained commercially. It, therefore, only depends upon the economic aspects as compared with those in other methods of control, whether the sugar industry will make full use of the nuclear method. However, other nuclear gauging methods, e.g. for weight and flow, still require further technical development or specially trained personnel. It is also worthwhile considering the use of radioactive tracers for process control or special investigations, as already exploited elsewhere.

#### Weight control

A gamma gauge has been successfully used in the Hawaiian sugar industry, as described by Burr and Payne<sup>1</sup> in 1954, for the continuous measuring of the weight of bagasse, moving in a free-falling stream from a conveyor belt, through which the gamma radiation from a caesium-137 source passes. The free falling stream eliminates uncertainty of the movement rate of the conveyor belt and a true blank reading is obtained every time the stream is interrupted. This technique gives a continuous and permanent record of milling performance which is of considerable value. The same detector signal which actuates the recorder can be used to actuate automatic controls regulating the cane fed into the crushers.

Caesium-137 was chosen rather than cobalt-60 since the crushed cane attenuates 18% of the caesium radiation and only 11% of the cobalt radiation. This increased attenuation improves the precision of the measurement. By selecting a source size that resulted in 10,000 counts per minute, the overall error in estimating mill loads was  $\pm 5\%$ .

Three different, commercially available, bagasse weighers were installed in Hawaiian factories for evaluation during the 1966 season, as described by Saxby<sup>8</sup>. Apart from minor technical problems they all operated well and gave satisfactory results, which were compared with milling figures obtained by the inferential method. Weight discrepancies of + 10%

to - 22.5% were found, with a resulting effect on mill extraction of - 0.5% to 1.5%. The installation of a reliable bagasse weigher was consequently considered essential to obtain accurate milling figures.

A similar type of gauge has also been developed to weigh raw sugar as it falls in a thin stream. The sugar absorbs about 25% of the radiation from a caesium-137 source and the weight of sugar is measured to  $\pm 1\%$ .

An expansion of this type of continuous weighing system is at present under investigation by the Atomic Energy Board, Pelindaba, for commercial exploitation. Using various radioisotope sources, with less penetrating radiations, the method is intended for a variety of materials used in South African industry.

#### Flow Measurement

Radionuclides have been used for the precise determination of the flow rates of liquids and gases, making use of the addition of a suitable radioactive solution to trace the flow of the fluid concerned. Flow rate measurement using radiotracers is becoming increasingly important as advantages and limitations in the operating characteristics of alternative systems become more apparent as a result of the increasing demand for higher accuracy and reliability over an ever widening range of flow rates. The books by Erwal *et al*<sup>3</sup> and by Gregory<sup>5</sup> include technical descriptions of nuclear flow measurement as well as examples of such applications. These techniques have already been applied in South Africa e.g. scientists of the Department of Water Affairs have recently received training at Pelindaba to enable the establishment of their own nuclear hydrological laboratory.

Under controlled conditions high accuracy and reliability, consistently within  $\pm 1\%$ , can be achieved for liquid flow measurement in closed conduits. Radiotracer methods require only small injection volumes and can be operated with virtually no loss in pressure. Injection and sampling probes can easily be designed into existing or new conduits at very small cost. Measurements can then be made at any time without interrupting the flow. In general, flow measurement over a range of  $10^9$  can be made using virtually the same equipment.

The principal disadvantages of isotope tracer methods for flow measurement arise from the discontinuous nature of the measurements and the relatively short half-life of the tracer which it may be necessary to use; this prohibits casual measurement unless a local supply of radioactivity is available. For both these reasons radiotracer methods are mainly recommended for flow measurement when highly accurate periodic measurements are required, and for calibrating conventional types of continuously operating flow meters.

Apart from the tracer techniques described above, methods, based on induced radioactivity by neutron irradiation, and which operate continuously without impeding the flow, are under development. Several systems of flow measurement and control, based on

the mechanical movement or rotation of a vane, have been improved by using a radioisotope as the indicating element.

#### Tracer Investigations

Although the radioisotopes of the elements C, H and O, constituting organic sugar, do not have suitable nuclear characteristics for tracer experiments, other radionuclides have been used to advantage in sugar production investigations.

Radioactive tracers have been used by Wramstedt<sup>12</sup> in Sweden to study the distribution of the solution and of the mud between the different zones and to determine the detention period in two Dorr thickeners. These are used to clarify the calcium carbonate slurry produced in the sugar beet extraction process, during which the unwanted compounds are removed from the sugar solution.

Separate experiments were made using labelled solutions and labelled mud. The liquid phase was labelled with sodium-24 (irradiated  $\text{NaHCO}_3$ ), which was found to remain in this phase after carbonation. The mud was labelled with lanthanum-140, which was co-precipitated as insoluble  $\text{La(OH)}_3$  during the carbonation. A small portion of the solution was taken out before carbonation and lanthanum-140 was added as lanthanum nitrate. In all experiments, the tracer was all added at once to the incoming slurry at the top of the thickener. The activity in the different tubes was recorded continuously by scintillation detectors.

In the experiments with the labelled liquid phase the activity appeared in the outlet from the top zone after 6 min, from the medium zone after 7.5 min, and from the bottom zone after 10 min. Integration of the resulting curves showed that 50% of the activity had left the thickener after 40 min, which agreed with the calculated detention time.

The activity curves for the mud tubes, when labelled mud was added to the incoming slurry, indicated flow rates in the three tubes: upper zone 230 l/min, medium zone, 150 l/min and bottom zone 120 l/min. In spite of the small flow from the bottom zone the mud passed this zone with the highest speed. Recirculation through an external loop of a small percentage (ca. 10%) of the slurry gave rise to a second peak on the activity curves.

These investigations have given valuable information on the flow characteristics of the two Dorr thickeners, which indicated that they differed considerably in detention characteristics for the solution, and in the mixing properties for the thickeners. The flow through the different zones was of particular interest; this gave an indication that the intermediate zone showed irregularities in comparison with the others.

A second study, as reported by Gregory<sup>4</sup>, was conducted in Australia to investigate the pattern of flow in a Bach subsider for raw sugar solutions. The hot raw solution after lime treatment enters through a single pipe feed line at the top and clarified solution is taken off by pipelines at six different levels. The solids are taken off at the base. About 5 millicuries of bromine-82 in solution was injected

into the feed line and the appearance of the tracer measured quantitatively by shielded scintillation counters on each of the six outlet pipes. Analysis of the distribution of activity with time in each line permitted a clear indication of the nature of the flow within the subsider.

The above example indicates the type of investigations, which have been conducted into sugar milling and refining in other countries. They represent the type of process control studies which can be fruitfully carried out on existing factories and, especially, on new installations such as the De Smet diffusion plant. Here, the problem exists of ensuring that the syrup from each juice distributor ends up in the correct hopper in the clarifying process.

### Conclusion

It is evident that the industrial application of sealed radioactive sources for the gauging of level, density, thickness, etc., is well-established in industry and is available on a normal commercial basis. However, the exploitation of these nuclear instruments still awaits recognition by the South African sugar manufacturing industry. This will depend on a careful re-appraisal of the economic benefits viz-a-viz the more conventional techniques of measurement and control. Whether ionising radiation will be able to solve additional problems, such as finding stones in the delivered cane, requires careful investigation.

However, it is in the field of radiotracer application where much remains to be done by the industrialist and research worker. With the availability of the nuclear reactor, SAFARI-1, and other isotope facilities of the Atomic Energy Board at Pelindaba, there is no reason why this ingenious method should not be exploited to the full by the South African sugar manufacturing industry.

### Acknowledgement

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**TABLE I**  
Sealed Sources in Use by South African Industry on 31st December, 1967

Type of Use	Number of Sources
Density gauging ... ..	108
Radiography ... ..	65
Weight control ... ..	65
Height control ... ..	57
Analysis ... ..	30
Calibration and research ... ..	28
Safety control ... ..	22
Moisture determination ... ..	21
Prospecting ... ..	3
<b>Total ... ..</b>	<b>399</b>

**TABLE II**  
Gamma Sources Commonly Used in Density and Thickness Gauges

Nuclide	Caesium-137	Cobalt-60
Half-life ... ..	30 years	5.3 years
Main Gamma Energies (MeV) ... ..	0.66 (82%)	1.17 (100%) 1.33 (100%)
Useful Range:		
mm Water ... ..	60-600	100-1,000
mm Aluminium ... ..	25-250	35-350
mm Iron ... ..	7-70	10-100

### APPENDIX

#### Isotopes and Radiation

##### Radioactivity

In order to explain the uses of radioisotopes and their ionising radiations, it is necessary to examine their physical properties. Such an explanation will be confined to radiations originating from radioactive material, although X-rays possess similar qualities, except in so far as origin is concerned.

The classic origin of the word "radioisotope" (radio=radiation, iso=the same, and topos=place) indicates that different isotopes of the same element occur in the same place in the Periodic System, i.e. as forms of the same element but emitting radiation. This instability is caused by an unfavourable combination of protons and neutrons, the two fundamental particles constructing the atomic nucleus.

The fact that every atom consists of a positive nucleus surrounded by orbiting negative electrons,

similar to the solar system but with electrostatic forces instead of gravitation and, naturally, a much smaller orbit of ca.  $10^{-8}$  cm diameter, forms part of elementary physics. In chemical reactions it is only the outer orbital electrons of the atoms concerned that react; the number of electrons present thus determines unequivocally which element it is. This number is, of course, equal to the number of positive protons in the nucleus, while a different number of neutrons serves to bind the strongly repellent protons by means of the thus far unexplained nuclear forces. An indication of the much stronger forces acting within the nucleus is found in the fact that nuclear energies are expressed in MeV, while the energies released by reactions of the orbital electrons (chemical, light, etc.) are of the order of a few electronvolts\*.

More than one number of neutrons is therefore possible without the chemical properties being affected, in forming the different isotopes of each element as indicated in the familiar Chart of Nuclides. Some of these are unstable and such radioisotopes change to more stable nuclei by the emission of energetic ionising radiations. This radioactive decay consists of the decomposition of individual nuclei independent of each other and it therefore obeys only the ordinary statistical laws, leading to an exponential decrease in activity. Each radionuclide has a characteristic possibility for the radioactive disintegration of its nuclei, which is observed as the "half-life", i.e. the time taken for half of its nuclei to decay. Thus, after a time equal to one half-life, only half of the original radioactivity\*\* remains; after two half-lives, one-quarter; after three half-lives, one-eighth, and so on.

Radionuclides can be prepared by nuclear reactions in particle accelerators (cyclotron, Van de Graaff, etc.), but the cheapest and easiest method is by means of a nuclear reactor such as SAFARI-1. In this case, the natural element is irradiated with an intense neutron flux and the stable nuclei may capture neutrons to form radioisotopes. Such isotope production is, however, limited to isotopes with an excess of neutrons†; proton-rich isotopes must be prepared by means of accelerators such as the CSIR cyclotron.

### *Ionising Radiation*

There are mainly three types of radiation arising from radioactive decay, namely alpha, beta and

\* The electronvolt is a unit of energy, equivalent to the amount of energy gained by an electron in passing through a potential difference of one volt ( $1 \text{ eV} = 1.6 \times 10^{-12} \text{ erg}$ ).

\*\* The unit of radioactivity is the curie which is equal to a decay rate of  $3.7 \times 10^{10}$  nuclear disintegrations per second.

† *Example:* Iron—the element with 26 orbital electrons and therefore 26 protons in the nucleus—appears in nature as four different stable isotopes:  $^{54}\text{Fe}$  (i.e. 54 nuclear particles (nucleons) and thus  $54 - 26 = 28$  neutrons),  $^{56}\text{Fe}$  (30 neutrons),  $^{57}\text{Fe}$  (31 neutrons) and  $^{58}\text{Fe}$  (32 neutrons), with relative occurrences of 5.84%, 91.68%, 2.17% and 0.31%, respectively. When iron is exposed to a neutron flux, neutron capture takes place to form  $^{55}\text{Fe}$ ,  $^{57}\text{Fe}$ ,  $^{58}\text{Fe}$  and  $^{59}\text{Fe}$ ; of these,  $^{55}\text{Fe}$  and  $^{59}\text{Fe}$  are unstable and undergo radioactive decay with half-lives of 2.9 years and 46 days, respectively.

gamma rays. An alpha particle is actually a fragment of the nucleus (comprising two protons and two neutrons), while a beta particle is an electron, which originates in the nucleus; gamma rays are similar to X-rays except that they are usually more penetrating (higher energy) and originate in the nucleus.

Because alpha and beta rays are actually particles, they can be comparatively easily absorbed; a few centimetres of air in the case of alphas and a few centimetres of water in the case of betas, are sufficient. Gamma radiation is, however, even more penetrating than X-rays and several centimetres of lead may be necessary to reduce the intensity; such absorption of individual gamma photons takes place exponentially.

Absorption\* in matter takes place mainly by interaction with the electrons, which are knocked out of their atomic orbits. When an electron has been displaced into another orbit, it can return to its original orbit with loss of excitation energy as light or X-radiation. If the electron has been removed completely out of the atom, the remaining atom has a shortage of negative charge and is called a positive ion. Because of this ionising process, alpha, beta and gamma rays are classified as ionising radiations. (The chance of a nuclear reaction occurring is much smaller and consequently unimportant as regards the absorption of radiation.)

### *Detection*

Detection of any radiation only takes place as the result of its effect on the instrument. The following effects are used in the different detecting methods:

- |            |  |
|------------|--|
| heat       | — temperature rise (calorimeter)                           |
| chemical   | — reaction (e.g. oxidation of ferrous to ferric sulphate)  |
|            | — photographic (blackening of film)                        |
| ionisation | — conduction (ionisation chamber)                          |
|            | — electrical pulse (Geiger-Müller or proportional counter) |
| light      | — fluorescence (scintillation counter)                     |

Large radiation doses are detected by calorimeters and by chemical reactions, and lower intensity radiation by ionisation chambers or photographic film. Individual rays are counted by Geiger or scintillation counters; apart from their remarkable sensitivity, the latter are also able to determine the energy of the radiation and can in this way help to identify the radionuclides.

### *Health Physics*

Because of their radiation properties it is clear that alpha and even beta radiations have only a local surface effect unless the radioactive material is present internally. By means of penetrating gamma rays, however, it is possible to irradiate the whole human body.

A large radiation dose (ca. 450 rems), administered to the whole body, can result in death. A dose smaller than approximately one-twentieth (25 rems) of the fatal dose cannot, however, be detected

\* The unit of absorbed radiation dose is the "rad" (= 100 ergs per gram), which is approximately equivalent to the earlier "roentgen" and also the biological "rem".

medically and physical methods of dose measurements are necessary. As in the case of sunburn, a considerably larger dose can be tolerated if applied gradually, thus giving the body an opportunity to recover between doses. It is also possible to apply large doses to parts of the body (cf. burns) without damaging the whole body.

In the present enlightened age, only the results of small doses should be of practical importance to the radiation worker. The damage to individual body cells can have long-term effects, such as the development of malignant growths several years after irradiation, genetic changes, etc. Although there is no scientific proof that there is not a minimum dose necessary to cause damage, it is assumed for the purpose of radiation protection that there is no such threshold. The International Commission on Radiological Protection, which was formed in 1928, lays down maximum permissible radiation exposures\*, as well as the maximum permissible concentrations of the different radionuclides in air and water, and these are accepted throughout the world as the basis for radiation protection.

### Radiation Protection

Practical radiation protection is based on the properties of the particular radionuclide, i.e. the half-life together with the nature (alpha, beta or gamma) and energy of the radiation, which determines the penetrating power and biological effect. The permitted exposure time can then be determined, taking into account the distance† from the source and also the necessary shielding. The health physicist has the task of weighing up these various factors: must an expensive apparatus of, say, R10,000, be built with the necessary shielding and remote control or can a worker be sent in quickly with a screwdriver?

Irradiation by external sources can normally be readily controlled because the person and source can easily be separated. Great care must, however, be taken to ensure that no radioactive material comes in contact with the body, either externally or internally. It is also important to note that the weight of radiotoxic material is very much lower than that of corresponding chemical poisons. As a result, the dangers associated with internal contamination must be eliminated by good housekeeping and diligent pre-planning.

Because ionising radiation cannot be detected by the ordinary senses, it is necessary to have suitable monitoring instruments. In addition, it is necessary to record the observed doses very carefully.

\* Permissible integrated dose in rems =  $5(N-18)$ , where  $N$  is the radiation worker's age in years; this total may not be accumulated at a higher rate than 3 rems per quarter. It is important to note that for planning purposes the formula leads to a maximum exposure rate of 100 milli-rems per week, i.e. 2.5 mR per hour for a 40-hour working week.

† The dose rate obeys the usual inverse square law, e.g. when a radioactive source is held at a distance of one centimetre the dose to the hands is 10,000 times greater than when tongs 1 metre in length are used.

For individual personnel dose measurement, use is made of the darkening of a piece of radiographic film as an indication of the exposure—the so-called film badge; to control the instantaneous dose, a pocket dosimeter can also be used. The registered personal dose should be kept as low as possible by following safe working methods.

The basis of all radiation protection is the monitoring of working areas with Geiger or scintillation counters and ionisation chambers. These instruments ensure that personnel exposures are kept to a minimum, as well as that no radioactive contamination of clean areas or persons takes place.

### Discussion

**Mr. Gunn** (in the chair): It appears that radioisotopes could be used to trace flow patterns through a diffuser.

**Mr. Buchanan:** What would the sources of error be in continuous weighing of bagasse when using the gamma ray technique?

**Dr. Basson:** I have no figures myself but others have quoted an accuracy of 1%. This could be limited by inaccuracies in the bulk of the bagasse, by geometrical errors and limitations placed on the activity of the source. The matter is at present under investigation and Americium-241 is being used which gives higher absorption than Caesium-137.

**Mr. du Toit:** The Experiment Station has been using an electron probe with excellent results. I would like to know what legal restrictions there would be in connection with using a radioisotope in bagasse?

**Dr. Basson:** The conditions imposed by the Atomic Energy Board, as statutory body, will depend on the qualifications of the person who would be handling the radioisotope, on available facilities, etc. Also, as a further safety precaution, a nuclide with a short half-life should preferably be used.

**Mr. Ashe:** Has the Government Assize Office accepted radioisotopes for use for measuring purposes in South African sugar factories?

**Dr. Basson:** No, as at present there is no suitable equipment available for this purpose.

**Dr. Matic:** Would not such an enormous amount of tracer have to be used in the bagasse as to make the cost prohibitive? We have used Carbon-14 in another investigation and the governing factor has been expense.

**Dr. Basson:** Carbon-14 requires special preparation and is therefore rather expensive. However, large volumes of material can be labelled with a radioactive tracer, e.g., we have carried out experiments at power stations in labelling water and steam in boilers and in gold mines in labelling water, pumped from underground, for determination of recirculation.

**Mr. Kamer:** Could radioisotopes be used to detect tramp iron in cane consignments? At present magnets, for instance, are used for this purpose.

**Dr. Basson:** They would not be effective in detecting small pieces of iron as the variation in overall density would not be much.

**Mr. Robinson:** Would it be possible to measure moisture in sugar, bearing in mind possible variations in crystal sizes?

**Dr. Basson:** Moisture measurements with neutrons is really a determination of the hydrogen content; furthermore the amount of air present would affect the measurement.

**Mr. O'Reilly:** Could a particular bundle of cane have an isotope placed in it so that it could be traced until that bundle was crushed?

**Dr. Basson:** There should be no scientific difficulty and various combinations of isotopes could be used. However, the financial aspects would have to be considered.

**Mr. Warne:** The Australians have used radio-isotopes in an endeavour to follow the circulation of massecuites in vacuum pans but they seemed to have difficulty in tracing the isotope, which was encased in a squash ball.

**Dr. Basson:** I cannot think why they should have had any difficulty. It is possible that the squash ball was not following the circulation of the massecuite.

**Dr. Matic:** The Australians were using an isotope with too short a life, and hope to repeat the experiment with a different type isotope.

**Mr. O'Reilly:** It might be possible to encase an isotope in a steel ball and place it in the cane bundle and then extract it by magnets so it could be used again.

**Dr. Basson:** The practical aspect of this would have to be studied. In the diamond industry isotopes are recovered and used again.