RADIOACTIVE MATERIALS IN NEW ZEALAND INDUSTRY

Certain materials "decay" at the atomic level over a period of time, giving off "radiation" in the form of energy or subatomic particles. This radiation can be harnessed and used for a variety of industrial applications. Some of the commonest of these which are used in New Zealand are listed below, although many others exist that are either only used to a small extent or used exclusively overseas.

Thickness, density and level gauges
By measuring the relative amounts of radiation reflected back and absorbed into a substance, it's thickness can be precisely determined. This is used for quality control in a variety of industries. Using more penetrating radiation and a thicker sample, the same technique can be used to determine the density of substances such as woodpulp or ironsand slurries, and a similar technique is used to determine the level of liquid in a closed container.

Elemental analysis
Different elements react differently when irradiated, thus changing the energy of the radiation beam reflected back off a surface. The elemental composition of a substance can be determined by comparing the initial radiation with the reflected radiation and consulting charts that list the characteristic changes made by different elements.

Static elimination
Radiation can be used to reduce the number of ions present in the air. This is useful for many industries, including the electronics and photography industries.

These examples are just a small selection, but this provides an idea of the scope of situations in which radiation is useful. However, radiation is also harmful to humans and thus it is important in all applications using radiation that this danger is minimised. This is done by limiting the time of exposure, distancing people from the radiation source and shielding them from it with a physical barrier. The substance the barrier is made of varies depending on the type of radiation involved, as what blocks some emissions will not block others, but is commonly lead. There is always a risk involved in using radiation (as there is with the natural cosmic radiation to which we are constantly exposed), but with these measures that risk can be minimised.

INTRODUCTION

Isotopes are atoms of the same element, but with different numbers of neutrons (same atomic number but different mass number). Some isotopes are unstable and decay over a period of time releasing high energy (ionising) radiation. The decay follows first-order kinetics and the rate of decay of an isotope is expressed as its half-life, the time taken for half or it to decay. Isotopes of short half-lives are not suitable for the uses described in this article. This radiation can be in the form of alpha, beta or gamma radiation (the nature of each of these forms are listed in **Table 1**). Neutron radiation also exists but, unlike the others, it is produced by a nuclear reaction rather than directly by decay. Most neutron sources are of the americium/beryllium type involving 0.5 - 500 GBq ^{241}Am[1], with the main reaction being:

$$ {}^{4}_{2}\alpha + {}^{9}_{4}\mathrm{Be} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}\mathrm{n} $$

When the energetic α and β particles or γ photons interact with matter they ionise it (i.e. knock electrons out of atoms in the matter and create positive ions). The electrons and the ions lead to radiation chemical products, and in living matter to biological damage. The penetrating power of α:β:γ particles or photons of the same energy is about 1:100:10 000. The energy of the particles is often measured in keV or MeV. (eV is the symbol for electron-volts.)

The fact that radiation ionises matter is the basis of many detector systems. Ionising a gas allows a small current to flow, and this current can be amplified and detected. Radiography depends on the darkening of photographic film.

Table 1 - The different types of radiation

Name	Symbol	Nature
alpha	α	Helium nucleus (2 neutrons, 2 protons)
beta	β	Single electron
gamma	γ	High energy electromagnetic radiation (γ-photons)
neutron	n	Single neutron

An extensive range of radionuclides (radioactive atoms) is used in industry, including ^{192}Ir, ^{3}H, ^{241}Am, ^{137}Cs, ^{85}Kr, ^{32}P, ^{90}Sr, ^{204}Tl, ^{60}Co, ^{147}Pm, ^{238}Pu, ^{226}Ra, ^{210}Po, and ^{63}Ni. These isotopes, when used as sealed radiation sources, have many different applications but are mainly used in gauging operations (e.g. finding out the depth of coatings), radiography, static elimination and industrial processing (sterilisation). Alpha, beta, gamma, and neutron radiations are all applied in industry.

INDUSTRIAL APPLICATIONS

Industrial applications of radioactive materials usually rely on the variation of the ability of substances to absorb or scatter radiation. The more dense a material, for example, the more effectively it will stop or scatter beta particles. By measuring beta particle transmission or the amount of backscatter, an indication of thickness or density can therefore be obtained, relative to that of a reference sample. The greater penetrating power of gamma rays is used for measurement of thicker or denser materials. Neutrons are slowed down, or *moderated*, very effectively by water, and so are suited to the measurement of moisture content.

Industrial applications of radioactive materials are described briefly below, while the principles involved are illustrated in **Figures 1 - 9**.

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[1] Unit of radioactivity: the *becquerel*, Bq. 1 Bq = one nuclear transformation per second. 1 megabecquerel, MBq = 10^6 Bq; 1 gigabecquerel, GBq = 10^9 Bq; 1 terabecquerel, TBq = 10^{12} Bq.

Thickness gauges

Thickness gauging involves the measurement of either the count rate due to backscattered beta particles (**Figure 1**), or to transmitted beta particle or gamma ray beam intensity (**Figure 2**). Krypton-85 is commonly used as a beta source, in amounts up to 1 GBq for backscatter and 40 GBq for transmission, while ^{241}Am is a common low-energy gamma source. Their application in industry is varied, and examples include controlling the thickness of chipboard, paper, coatings, and plastic sheet.

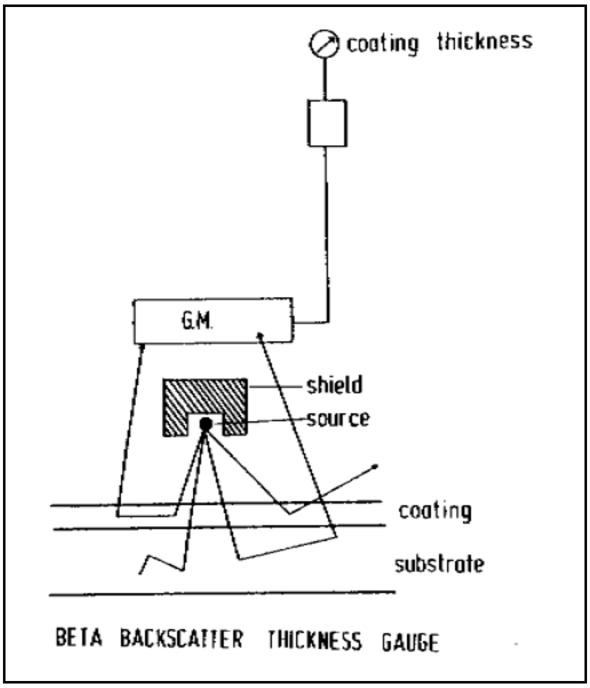

Figure 1

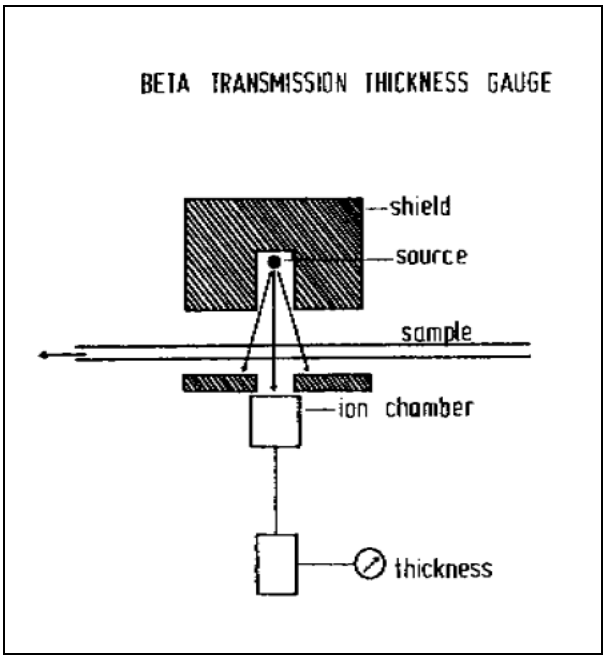

Figure 2

Density gauges

Density gauges use the more penetrating gamma radiation from ^{60}Co or ^{137}Cs for the measurement of density of materials too heavy or thick for measurement with beta thickness gauges. Again, the decrease in transmitted beam intensity (**Figure 3**), or the amount of backscatter (**Figure 4**), provides a measure of sample density. Source activities involved are up to 2 GBq of ^{137}Cs for backscatter, and up to 40 GBq for transmission. Examples of this application include monitoring pipeline density of ironsand slurries or sewage, and the controlling of pulp density in wood-pulp mills. Some beta sources are used for density gauging in smaller applications such as controlling cigarette firmness.

Level gauges

Level gauging is an extension of density monitoring. A gamma source, usually ^{60}Co or ^{137}Cs, is used to control levels in various industrial processes as depicted in **Figure 5**. In the steel industry, for example, level detectors control the plant in the continuous casting of steel, while in the beverage industry they are used to automatically reject under-filled cans (^{241}Am is used in the latter case).

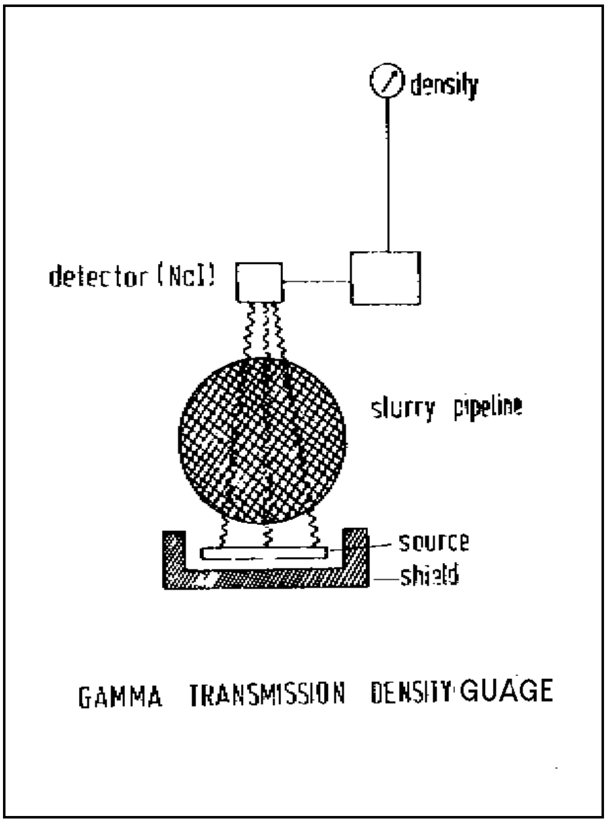

Figure 3

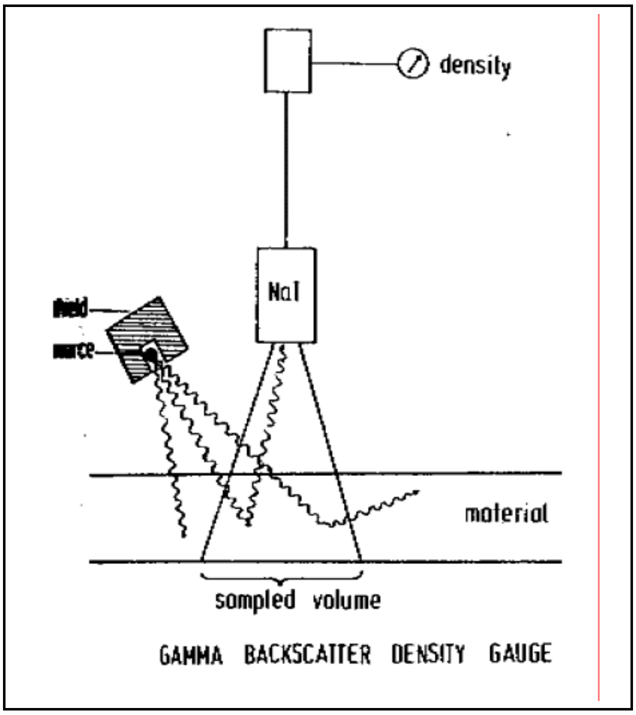

Figure 4

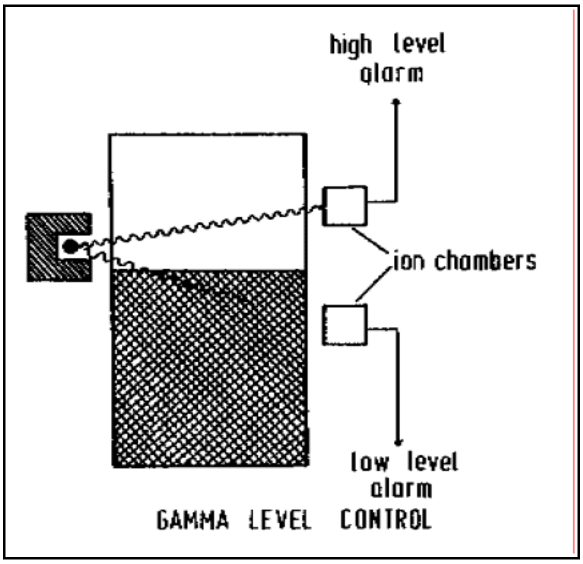

Figure 5

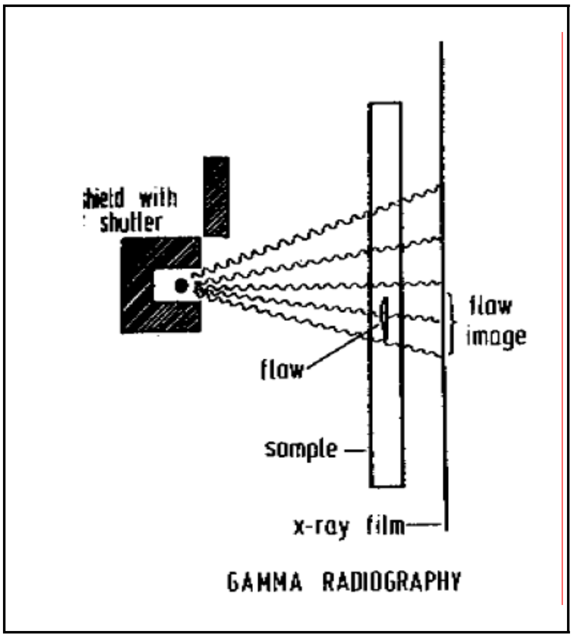

Figure 6

Gamma radiography

Gamma radiation sources used in industrial radiography (**Figure 6**) are of much higher activity than those used in most other applications, and therefore cause most concern as potential radiation hazards. The most commonly used radiation source is ^{192}Ir, with activities up to 4 TBq. Examples of this application include the checking of materials and welds on pipelines and construction projects. Aircraft engines and components are also checked by this method.

Elemental analysis
Gamma-emitting radionuclides are also used in x-ray fluorescence analysis (**Figure 7**), where a source such as ^{238}Pu (typically 1 GBq), ^{147}Pm, or ^{241}Am is used to induce secondary x-ray emission in the sample under study. Emitted x-ray energies and intensities then define the sample composition. This technique is also used to measure the thickness of coatings of one element upon another, as in the zinc plating of steel.

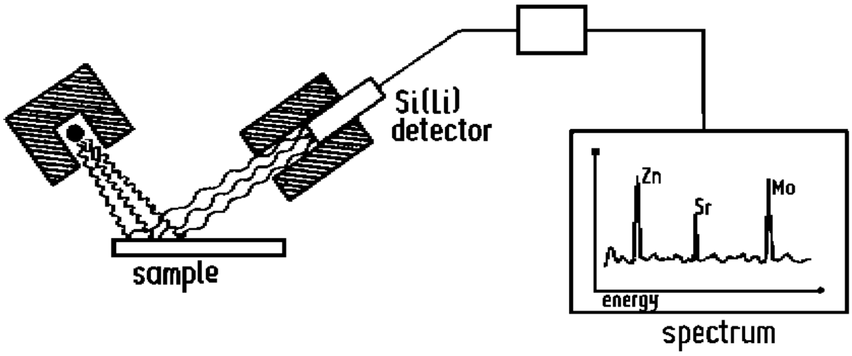

Figure 7 - X-ray fluorescence spectroscopy

Soil moisture and density gauges
Soil moisture/density gauges are combination gauges which use a ^{137}Cs gamma source for backscatter density measurement, and an Am/Be fast neutron source for moisture measurement. A BF_3 proportional counter detects the moderated, backscattered neutrons, while a geiger tube detects backscattered gamma radiation. Sources and detectors are mounted in a probe which is inserted into the soil, as depicted in **Figure 8**. Gauges of this type are used in agricultural studies, road building, civil engineering, and in well-logging.

Static elimination
The generation of static charge can cause problems in the handling of materials in many industrial processes. An alpha-emitting radionuclide such as ^{210}Po (typically 6 GBq) is used to reduce the problem by creating a region of ionised, and hence electrically conducting, air through which the charge material is passed, as depicted in **Figure 9**. This technique is used in the printing, plastics, and fabrics industries, in film processing (to keep dust off negatives), and in the electronics industry where static discharges may damage components.

Other applications
Other applications of radioactive materials in New Zealand industry include:

- radiation sterilisation, where a 7500 TBq ^{60}Co gamma radiation source is used to sterilise medical supplies
- smoke detection, where ^{241}Am alpha sources are used to create ionised air, and hence current flow between electrodes in the detector, with the current being reduced or stopped by the presence of ion-scavenging smoke particles

- luminous devices, using beta-emitting ^{147}Pm or ^{3}H
- gas chromatographs, where electron-capture detectors use ^{63}Ni or ^{3}H.

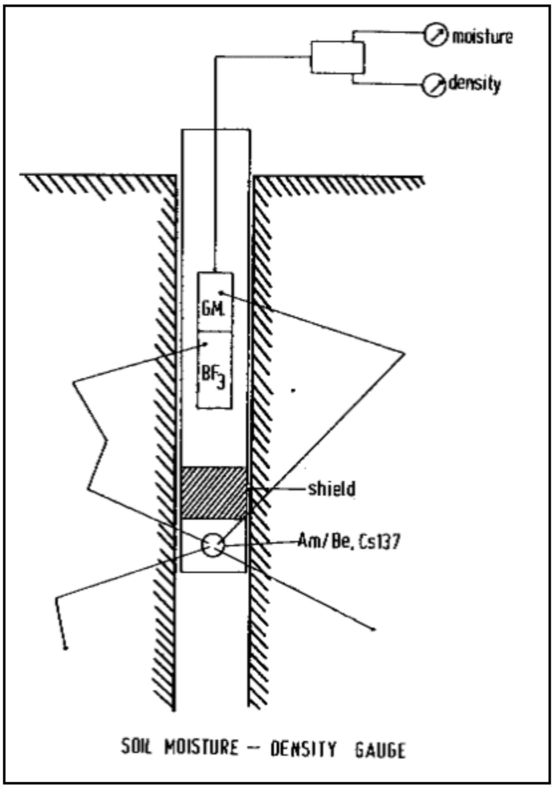

Figure 8

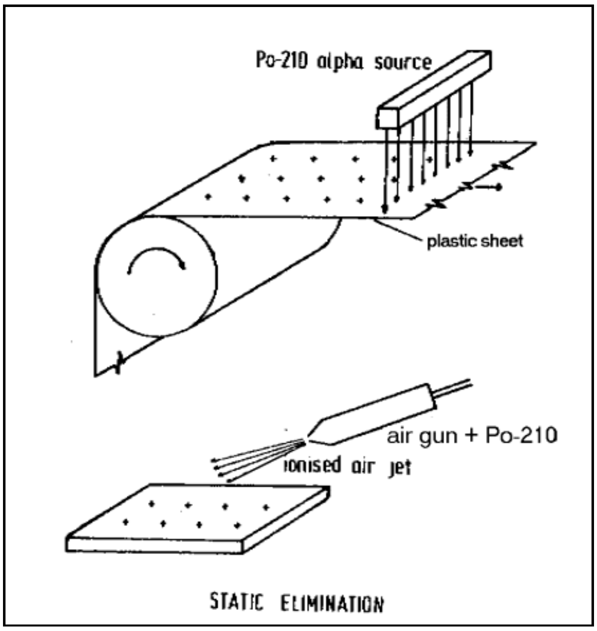

Figure 9

INDUSTRIAL RADIATION HAZARDS

Biological effects of radiation resulting from ionisation, and consequent changes in cell chemistry, may occur upon the absorption of radiation. All radiation may produce some effect, but whether or not this is significantly detrimental, or even detectable, depends on the organ irradiated, the dose, and the duration of exposure.

At doses of the order of 0.2 Sv[2], slight changes may be detected in human blood, even though there may be no clinical symptoms; while the mean lethal dose (50% mortality) is approximately 4 Sv delivered to the whole body over a short period. Maximum permissible doses for radiation workers have been determined assuming that small doses produce correspondingly smaller effects and that there is no dose, however small, which might not have some effect. The dose limit set by the International Commission on Radiological Protection, for people exposed occupationally, is 0.02 Sv/year (averaged over 5 years, or 0.05 Sv in any one year), while for members of the public it is 0.001 Sv/y. These doses may be put into perspective by considering the natural background radiation dose, to which we are all

[2] Unit of dose: the *sievert*, Sv: a measure of *effective dose* calculated from absorbed dose, a quality factor pertaining to type of radiation, and a weighting factor for the organ irradiated.

continually exposed, is about 0.002 Sv/y. The occupational group with the highest exposure in New Zealand is actually aircraft flight crews, who are exposed to elevated levels of cosmic radiation at high altitudes, with annual exposures in the range 0.003 - 0.007 Sv/y depending on routes travelled.

The fundamental principle in radiation protection is that all radiation doses must be kept to a minimum, and the control of radioactive materials in industry is therefore so stringent that there is little chance of workers receiving more than the 0.02 Sv/y dose limit.

There are three basic protective principles: time, distance, and shielding. Time of exposure and distance from source are largely under operator control, and so are subject to human error. In practice, therefore, industrial instruments include sufficient built-in shielding to ensure that no additional control is required and that the equipment is safe under all normal conditions. The exception to this is industrial radiography, where large sources and intense radiation beams may be involved. Built-in shielding cannot be relied on exclusively in that case so radiographers must be specially trained and wear personal dosimeters to record the dose received.

Sealed radiation sources of the type used in industry give rise to a potential hazard from external radiation, rather than internal irradiation (which in some cases is potentially more hazardous) which would arise through ingestion or inhalation of radioactive materials, provided source integrity is not in doubt. Source encapsulation must be designed to ensure that under accident or adverse conditions it cannot be damaged enough to release radioactive materials. This is relatively easy to ensure with gamma radiation sources where the radiation is penetrating enough to pass through the encapsulating materials, but is more difficult with beta sources, and particularly difficult with alpha sources where any significant encapsulation would render the source ineffective due to the low penetrating power of the radiation. Because of the often harsh environment in industrial conditions, therefore, sources are regularly inspected for damage and replaced when aged. The frequency of inspection depends on source robustness, the working environment, the physical and chemical form of the radionuclide, its half-life, and toxicity.

The shielding requirements, inspection routines, and the need for operators of irradiating equipment to be licensed, work together to ensure that although there is a potential hazard wherever radiation sources are used, the actual hazard is small compared to other more common and generally-accepted hazards encountered in life.

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