Radioisotopes in Industry

(February 2010)

- Modern industry uses radioisotopes in a variety of ways to improve productivity and, in some cases, to gain information that cannot be obtained in any other way.
- Sealed radioactive sources are used in industrial radiography, gauging applications and mineral analysis.
- Short-lived radioactive material is used in flow tracing and mixing measurements.
- Gamma sterilisation is used for medical supplies, some bulk commodities and, increasingly, for food preservation.

Nuclear techniques are increasingly used in industry and environmental management. The continuous analysis and rapid response of nuclear techniques, many involving radioisotopes, mean that reliable flow and analytic data can be constantly available. This results in reduced costs with increased product quality.

Neutron Techniques for Analysis

Neutrons can interact with atoms in a sample causing the emission of gamma rays which, when analysed for characteristic energies and intensity, will identify the types and quantities of elements present. The two main techniques are Thermal Neutron Capture (TNC) and Neutron Inelastic Scattering (NIS). TNC occurs immediately after a low-energy neutron is absorbed by a nucleus, NIS takes place instantly when a fast neutron collides with a nucleus.

Most commercial analysers use californium-252 neutron sources together with sodium iodide detectors and are mainly sensitive to TNC reactions. Other use Am-Be-241 sources and bismuth germanate detectors, which register both TNC and NIS. NIS reactions are particularly useful for elements such as C, O, Al & Si which have a low neutron capture cross section. Such equipment is used for a variety on on-line and on-belt analysis in the cement, mineral and coal industries.

A particular application of NIS is where a probe containing a neutron source can be lowered into a bore hole where the radiation is scattered by collisions with surrounding soil. Since hydrogen (the major component of water) is by far the best scattering atom, the number of neutrons returning to a detector in the probe is a function of the density of the water in the soil.

To measure soil density and water content, a portable device with an americium-241-beryllium combination generates gamma rays and neutrons which pass through a sample of soil to a detector. (The neutrons arise from alpha particles interacting with Be-9.) A more sophisticated application of this is in borehole logging.

Gamma & X-ray Techniques in Analysis

Gamma ray transmission or scattering can be used to determine the ash content of coal on line on a conveyor belt. The gamma ray interactions are atomic number dependant, and the ash is higher in atomic number than the coal combustible matter. Also the energy spectrum of gamma rays which have been inelastically scattered from the coal can be measured (Compton Profile Analysis) to indicate the ash content.
X-rays from a radioactive element can induce fluorescent x-rays from other non-radioactive materials. The energies of the fluorescent x-rays emitted can identify the elements present in the material, and their intensity can indicate the quantity of each element present.

This technique is used to determine element concentrations in process streams of mineral concentrators. Probes containing radioisotopes and a detector are immersed directly into slurry streams. Signals from the probe are processed to give the concentration of the elements being monitored, and can give a measure of the slurry density. Elements detected this way include iron, nickel, copper, zinc, tin and lead.

X-ray Diffraction (XRD) is a further technique for on-line analysis but does not use radioisotopes.

**Gamma Radiography**

Gamma Radiography works in much the same way as x-rays screen luggage at airports. Instead of the bulky machine needed to produce x-rays, all that is needed to produce effective gamma rays is a small pellet of radioactive material in a sealed titanium capsule.

The capsule is placed on one side of the object being screened, and some photographic film is placed on the other side. The gamma rays, like x-rays, pass through the object and create an image on the film. Just as x-rays show a break in a bone, gamma rays show flaws in metal castings or welded joints. The technique allows critical components to be inspected for internal defects without damage.

Gamma sources are normally more portable than x-ray equipment so have a clear advantage in certain applications, such as in remote areas. Also while x-ray sources emit a broad band of radiation, gamma sources emit at most a few discrete wavelengths. Gamma sources may also be much higher energy than all but the most expensive x-ray equipment, and hence have an advantage for much radiography. Where a weld has been made in an oil or gas pipeline, special film is taped over the weld around the outside of the pipe. A machine called a “pipe crawler” carries a shielded radioactive source down the inside of the pipe to the position of the weld. There, the radioactive source is remotely exposed and a radiographic image of the weld is produced on the film. This film is later developed and examined for signs of flaws in the weld.

X-ray sets can be used when electric power is available and the object to be x-rayed can be taken to the x-ray source and radiographed. Radioisotopes have the supreme advantage in that they can be taken to the site when an examination is required - and no power is needed. However, they cannot be simply turned off, and so must be properly shielded both when in use and at other times.

Non-destructive testing is an extension of gamma radiography, used on a variety of products and materials. For instance, ytterbium-169 tests steel up to 15 mm thick and light alloys to 45 mm, while iridium-192 is used on steel 12 to 60 mm thick and light alloys to 190 mm.

**Gauging**

The radiation that comes from a radioisotope has its intensity reduced by matter between the radioactive source and a detector. Detectors are used to measure this reduction. This principle can be used to gauge the presence or the absence, or even to measure the quantity or density, of material between the source and the detector. The advantage in using this form of gauging or measurement is that there is no contact with the material being gauged.
Many process industries utilise fixed gauges to monitor and control the flow of materials in pipes, distillation columns, etc, usually with gamma rays.

The height of the coal in a hopper can be determined by placing high energy gamma sources at various heights along one side with focusing collimators directing beams across the load. Detectors placed opposite the sources register the breaking of the beam and hence the level of coal in the hopper. Such level gauges are among the most common industrial uses of radioisotopes.

Some machines which manufacture plastic film use radioisotope gauging with beta particles to measure the thickness of the plastic film. The film runs at high speed between a radioactive source and a detector. The detector signal strength is used to control the plastic film thickness.

In paper manufacturing, beta gauges are used to monitor the thickness of the paper at speeds of up to 400 m/s.

When the intensity of radiation from a radioisotope is being reduced by matter in the beam, some radiation is scattered back towards the radiation source. The amount of ‘backscattered’ radiation is related to the amount of material in the beam, and this can be used to measure characteristics of the material. This principle is used to measure different types of coating thicknesses.

**Gamma Sterilisation**

Gamma irradiation is widely used for sterilising medical products, for other products such as wool, and for food. Cobalt-60 is the main isotope used, since it is an energetic gamma emitter. It is produced in nuclear reactors, sometimes as a by-product of power generation.

Large-scale irradiation facilities for gamma sterilisation are used for disposable medical supplies such as syringes, gloves, clothing and instruments, many of which would be damaged by heat sterilisation. Such facilities also process bulk products such as raw wool for export from Australia, archival documents and even wood, to kill parasites. Currently ANSTO in Australia sterilises up to 25 million Queensland fruit fly pupae per week for NSW Agriculture by gamma irradiation. See also *The Peaceful Atom*.

Smaller gamma irradiators are used for treating blood for transfusions and for other medical applications.

Food preservation is an increasingly important application, and has been used since the 1960s. In 1997 the irradiation of red meat was approved in USA. Some 41 countries have approved irradiation of more than 220 different foods, to extend shelf life and to reduce the risk of food-borne diseases.

**Scientific Uses**

Radioisotopes are used as tracers in many research areas. Most physical, chemical and biological systems treat radioactive and non-radioactive forms of an element in exactly the same way, so a system can be investigated with the assurance that the method used for investigation does not itself affect the system. An extensive range of organic chemicals can be produced with a particular atom or atoms in their structure replaced with an appropriate radioactive equivalent.
Using tracing techniques, research is conducted with various radioisotopes which occur broadly in the environment, to examine the impact of human activities. The age of water obtained from underground bores can be estimated from the level of naturally occurring radioisotopes in the water. This information can indicate if groundwater is being used faster than the rate of replenishment. Trace levels of radioactive fallout from nuclear weapons testing in the 1950s and 60s is now being used to measure soil movement and degradation. This is assuming greater importance in environmental studies of the impact of agriculture.

**Tracing/Mixing Uses**

Even very small quantities of radioactive material can be detected easily. This property can be used to trace the progress of some radioactive material through a complex path, or through events which greatly dilute the original material. In all these tracing investigations, the half-life of the tracer radioisotope is chosen to be just long enough to obtain the information required. No long-term residual radioactivity remains after the process.

Sewage from ocean outfalls can be traced in order to study its dispersion. Small leaks can be detected in complex systems such as power station heat exchangers. Flow rates of liquids and gasses in pipelines can be measured accurately, as can the flow rates of large rivers.

Mixing efficiency of industrial blenders can be measured and the internal flow of materials in a blast furnace examined. The extent of termite infestation in a structure can be found by feeding the insects radioactive wood substitute, then measuring the extent of the radioactivity spread by the insects. This measurement can be made without damaging any structure as the radiation is easily detected through building materials.

**Wastes**

Industries utilise radioactive sources for a wide range of applications. When the radioactive sources used by industry no longer emit enough penetrating radiation for them to be of use, they are treated as radioactive waste. Sources used in industry are generally short-lived and any waste generated can be disposed of in near-surface facilities.

Some industrial activities involve the handling of raw materials such as rocks, soils and minerals that contain naturally occurring radioactive materials. These materials are known by the acronym "NORM". Industrial activity can sometimes concentrate these materials and therefore enhance their natural radioactivity (hence the further acronym: TENORM - technically-enhanced NORM). This may result in:

- A risk of radiation exposure to workers or the public
- Unacceptable radioactive contamination of the environment
- The need to comply with regulatory waste disposal requirements

The main industries that result in NORM contamination are:

Oil and gas operations

Oil and gas exploration and production generates large volumes of water containing dissolved minerals. These minerals may be deposited as scale in piping and oil field equipment or left as residues in evaporation lagoons. Occasionally the radiation dose from equipment contaminated with mineral deposits may present a hazard. More significantly contaminated equipment and the scale removed from it may be classified as radioactive waste. Oil and gas operations are the main...
sources of radioactive releases to waters north of Europe for instance.

Coal burning
Most coal contains uranium and thorium, as well as other radionuclides. The total radiation levels are generally about the same as in other rocks of the earth’s crust. Most emerge from a power station in the light flyash. Some 99% of flyash is typically retained in a modern power station (90% in some older ones) and this is buried in an ash dam. Around 280 million tonnes of coal ash is produced globally each year.

Phosphate Fertilisers
The processing of phosphate rock to produce phosphate fertilizers (one end product of the phosphate industry) results in enhanced levels of uranium, thorium and potassium.

Process and Waste Water Treatment
Radionuclides are leached into water when it comes into contact with uranium and thorium bearing rocks and sediments. Water treatment often uses filters to remove impurities. Hence, radioactive wastes from filter sludges, ion-exchange resins, granulated activated carbon and water from filter backwash are part of NORM.

Scrap metal industry
Scrap metal from various process industries can also contain scales with enhanced levels of natural radionuclides. The exact nature and concentration of these radionuclides is dependent on the process from which the scrap originated.

Metal smelting sluds
Metal smelting slags, especially from tin smelting, may contain enhanced levels of uranium and thorium series radionuclides.

Research
Following the operation of a particle accelerator, the facility will generally be decommissioned. As radioactive materials will be present in the facility, these must be treated as radioactive wastes and handled accordingly. Following a 40 year operation of one of the new generation of particle accelerators, the volume of decommissioning waste and activity is expected to be within the same order of magnitude as for a 1 GW(e) nuclear power plant which has operated over 40 years. However, it should be noted that the concentration of radioactivity is more evenly distributed in the case of such an accelerator facility.

Radiation sources utilised within universities and research institutions also require appropriate management and disposal. Many sources are of low activity and/or short half-life. However some exceptions include high-level long-lived sources such as Radium-226 and Americium-241 used in biological and or agricultural research. These require long-term management and disposal as Intermediate-Level Wastes (ILW).

Industrial Radioisotopes

Naturally-occurring radioisotopes:

Carbon-14: Used to measure the age of water (up to 50,000 years)

Chlorine-36: Used to measure sources of chloride and the age of water (up to 2 million years)
Lead-210: Used to date layers of sand and soil up to 80 years

Tritium (H-3): Used to measure 'young' groundwater (up to 30 years)

**Artificially-produced radioisotopes:**

Americium-241:
Used in backscatter gauges, smoke detectors, fill height detectors and in measuring ash content of coal.

Caesium-137:
Used for radiotracer technique for identification of sources of soil erosion and deposition, in density and fill height level switches.

Chromium 57:
Used to label sand to study coastal erosion.

Cobalt-60, Lanthanum-140, Scandium-46, Silver-110m, Gold-198:
Used together in blast furnaces to determine resident times and to quantify yields to measure the furnace performance.

Cobalt-60:
Used for gamma sterilisation, industrial radiography, density and fill height switches.

Gold-198 & Technetium-99m:
Used to study sewage and liquid waste movements, as well as tracing factory waste causing ocean pollution, and to trace sand movement in river beds and ocean floors.

Gold-198:
Used to label sand to study coastal erosion.

Hydrogen-3 (Tritiated Water): Used as a tracer to study sewage and liquid wastes

Iridium-192
Used in gamma radiography to locate flaws in metal components.

Krypton-85:
Used for industrial gauging.

Manganese-54:
Used to predict the behaviour of heavy metal components in effluents from mining waste water.

Nickel-63
Used in light sensors in cameras and plasma display, also electronic discharge prevention and in electron capture detectors for thickness gauges.

Selenium-75:
Used in gamma radiography and non-destructive testing.

Strontium-90:
Used for industrial gauging.

Thallium-204:
Used for industrial gauging.

Ytterbium-169:
Used in gamma radiography and non-destructive testing.

Zinc-65:
Used to predict the behaviour of heavy metal components in effluents from mining waste water.

What Are Radioisotopes?

Many of the chemical elements have a number of isotopes. The isotopes of an element have the same number of protons in their atoms (atomic number) but different masses due to different numbers of neutrons. In an atom in the neutral state, the number of external electrons also equals the atomic number. These electrons determine the chemistry of the atom. The atomic mass is the sum of the protons and neutrons. There are 82 stable elements and about 275 stable isotopes of these elements.

When a combination of neutrons and protons, which does not already exist in nature, is produced artificially, the atom will be unstable and is called a radioactive isotope or radioisotope. There are also a number of unstable natural isotopes arising from the decay of primordial uranium and thorium. Overall there are some 1800 radioisotopes.

At present there are up to 200 radioisotopes used on a regular basis, and most must be produced artificially.

Radioisotopes can be manufactured in several ways. The most common is by neutron activation in a nuclear reactor. This involves the capture of a neutron by the nucleus of an atom resulting in an excess of neutrons (neutron rich).

Some radioisotopes are manufactured in a cyclotron in which protons are introduced to the nucleus resulting in a deficiency of neutrons (proton rich).

The nucleus of a radioisotope usually becomes stable by emitting an alpha and/or beta particle. These particles may be accompanied by the emission of energy in the form of electromagnetic radiation known as gamma rays. This process is known as radioactive decay.

Radioisotopes have very useful properties: radioactive emissions are easily detected and can be tracked until they disappear leaving no trace. Alpha, beta and gamma radiation, like x-rays, can penetrate seemingly solid objects, but are gradually absorbed by them. The extent of penetration depends upon several factors including the energy of the radiation, the mass of the particle and the density of the solid. These properties lead to many applications for radioisotopes in the scientific, medical, forensic and industrial fields.

Sources:
ANSTO
ANA 2001 conference papers.
Lowenthal & Airey 2001, Practical Applications of Radioisotopes and Radiation, Cambridge UP.
Modern industry uses radioisotopes in a variety of ways to improve productivity and, in some cases, to comply with regulatory waste disposal requirements. Gamma sterilisation is used for medical supplies, some bulk commodities and, increasingly, for industrial sterilisation processes. This method involves the use of gamma radiation to sterilise products. Alpha, beta and gamma radiation, like x-rays, are forms of electromagnetic radiation. These particles may be accompanied by the emission of energy in the form of electromagnetic waves or particles. Radioisotopes have very useful properties: radioactive emissions are easily detected and can be used to track substances or processes. For example, they are used in nuclear medicine to detect and treat cancer, in food production to ensure quality control, and in environmental studies to track the movement of radioactive materials in the environment.

Radioisotopes can be used in various applications, such as in the field of nuclear medicine, where they are used to treat cancer and other diseases. They are also used in agriculture to study plant growth and in industry to improve productivity and safety. Radioisotopes are used in the production of medicines, and they are also used in the treatment of chronic and acute diseases. They are used in environmental studies to track the movement of radioactive materials in the environment and to study the impact of nuclear accidents. Radioisotopes are also used in industry to improve productivity and safety, and they are used in the production of medicines and in the treatment of chronic and acute diseases. Radioisotopes are used in agriculture to study plant growth and in industry to improve productivity and safety.