RADIOISOTOPES

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A collection of articles which describe briefly some applications of the Commission's radioisotope research and production.

by

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GLOSSARY

Accelerator: A device which gives high velocity to charged particles (usually electrons or protons). The particles are used as projectiles in which their effect on 'target' materials is used as a means of studying the structure of the atom.

Alpha particle: Highly energetic positively charged helium atom emitted during radioactive decay of certain heavy elements, e.g. radium.

Beta particle: An electron of either sign which has been emitted by an atomic nucleus or neutron in the process of a transformation.

Beta rays: Streams of beta particles.

Cosmic rays: Highly energetic rays or atomic particles from outer space.

curie: The unit of radioactivity, the amount of radioactive material in which 3.7×10^{10} disintegrations per second occur. (Approximately equal to the activity of 1 gram of radium.)

Electron: A fundamental particle with a negative electric charge. Electrons are grouped round the nuclei of atoms in several possible orbital shells.

Gamma radiation: A form of electro-magnetic radiation, similar to light or X-rays, distinguished by its high energy and penetrating power. Gamma radiation is emitted by the nuclei of radioactive substances during decay.

Half-life: The time taken for the activity of a radioactive substance (or radioisotope) to decay to half its original value. This half-life is a distinguishing characteristic of a radioisotope and ranges from fractions of seconds to many millions of years. For example, nitrogen 13 : 10 minutes; cobalt 60 : 5.27 years; uranium 238 : 4.5 billion years.

Ionising radiation: Radiation which knocks electrons from atoms during its passage, thereby leaving electrically charged particles (ions) in its path; whence ionisation.

Irradiation: Exposure to ionising radiation.

Linear accelerator: Large device for accelerating electrons or positive ions up to nearly the speed of light.

Neutron: A nuclear particle having no electric charge and the approximate mass of a hydrogen nucleus.

Radiation: The emission of radiant energy from a source.

Radioactive atom: One which decays spontaneously into another species usually by emission of an alpha or beta particle accompanied by gamma or X-rays. Activity may be natural or induced. The spontaneous emission of such radiation is known as radioactivity.

Radiography: The examination of objects by passing X-, gamma or neutron radiation through them and photographing the shadows cast.

Radiotherapy: Treatment of disease by use of ionising radiation.

STERILISATION OF PHARMACEUTICAL PRODUCTS

The fact that radiation can be dangerous to life does not need any emphasis in the present day controversy over nuclear power and uranium mining. However, this fact can be used to advantage in killing bacteria, i.e. in sterilisation of medical and pharmaceutical products, and a very extensive industry is now established for doing this.

A few years ago when the doctor gave an injection he used a needle and syringe which was part of the permanent equipment of the clinic. After use they were carefully washed and resterilised before being used again. Nowadays he takes a new syringe complete with needle from a sealed sterile pack, uses it once and, after destroying the needle to prevent subsequent misuse, discards the used syringe. These complete syringes, which can be made very inexpensively, are sterilised after packing by passing them through an intense beam of radiation from cobalt 60, a radioisotope made artificially in nuclear reactors.

The new method has many advantages. The sterilisation procedure is much more effective, since the cost of the disposable syringe and needle is only a fraction of the cost of resterilisation. As the needle is only used once it will be sharp, whereas after a few applications, the old style hypodermic needles tended to become blunt and hurt the patient.

A whole range of pharmaceutical products is now sterilised in this way including surgical, gynaecological and theatre kits, sutures, blood transfusion equipment, catheters, some drugs and ointments and some of the radiopharmaceutical products of the Australian Atomic Energy Commission (AAEC). The major advantages of this procedure are economies in costs, considerably less cross infection and the fact that the sealed sterile product can be kept for long periods "on the shelf" ready for instant use.

The first large scale plant in the world for radiation sterilisation was built by the Westminster Carpet Company in Melbourne in 1960 to sterilise imported goat hair against anthrax infection. When the demand for goat hair ceased, owing to changes in carpet manufacture, the very large capacity of this plant was turned over to pharmaceutical product sterilisation. Modern developments in sterilisation plant eventually made this original installation obsolete and it was closed down in February 1976. The demand for disposable sterile medical products is now met in Australia by two large irradiators specially built for this purpose, one in Sydney and one in Melbourne.

RADIOISOTOPES AND DIAGNOSTIC MEDICINE

In recent years a new medical speciality has been developed called nuclear medicine which is now playing a very important part in the diagnosis of diseases. A considerable proportion of the radioactive products used for this work in Australia are made by the AAEC. In 1976-7 over 36 thousand shipments of radioisotopes with a total value of about 1.3 million dollars were made to hospitals. When it is realised that each shipment may contain sufficient material for 5 or 6 patients and that at least as many shipments are imported from overseas, it can be seen that nuclear medicine is involved in the diagnoses of more than 250,000 patients per year. At present in Australia there are forty-five nuclear medicine centres mainly in the larger cities; however centres are being established in some of the large country hospitals.

The way in which these products work depends on the fact that when certain biologically active compounds are injected into the blood stream, they concentrate in an organ of the body such as the liver, brain, kidneys, lungs, bone, heart, etc, depending on the nature and chemistry of the compound. Such compounds can be made containing (or 'labelled' with) a radioisotope. Various instruments are available, of which the most common is the gamma ray camera, which can be used to actually photograph the extent and function of the organ concerned by the radiation emitted. The amount of radioactivity required is extremely small and the procedure has no more risk than an ordinary X-ray examination. Most of the products used involve radioisotopes with very short life times and their activity is fully spent in a few hours. The picture obtained enables the diagnostician to get extremely valuable information about the condition and function of the organs concerned and this is all achieved without any pain or discomfort to the patient. The technique can be used for diagnosis of brain tumours, bone cancers, liver disease, clots in the lung, gall bladder function, kidney function, the effectiveness of kidney transplants and many other important diagnostic procedures. Recent developments include a method of measuring heart damage after heart attack.

Many of the radioactive products used for this purpose are made at the Commission's Research Establishment. Most of them have an effective life of only about 24 hours. The Commission ensures that they are available for daily use in every capital city in Australia and in five other cities by despatching shipments on overnight planes for use the next day. A very complex and sophisticated organisation is behind the production of these materials for not only must they be made and used very quickly because of their short life, but they must be manufactured under intensive quality and purity control to ensure that there is no danger of infection or other reaction when they are injected into the blood stream of a patient.

This application of radioisotopes is making a tremendous contribution to the quality of our lives through improved diagnosis of illness and disease. At the present rate of usage it is estimated that in Australia one person in three will be involved in a radioisotope diagnostic procedure some time in their life.

THERAPEUTIC USES OF RADIOISOTOPES

The use of ionising radiation for therapeutic applications, particularly for treatment of cancer, has been known for many years. This has led to the development of more and more powerful X-ray machines and electron accelerators for the generation of suitable radiation for this type of treatment. In recent years the gamma rays from the radioisotope cobalt 60, which are very much like X-rays, have been used for radiotherapy. A very strong source of cobalt 60 is enclosed in a large heavily shielded container with an opening covered by a remotely operated shutter which permits a small pencil beam of radiation to be emitted under precisely controlled conditions. Cobalt 60 is a relatively inexpensive, convenient and useful source of radiation for this purpose. Since 1960 the AAEC has supplied 48 radiotherapy sources of cobalt 60, mainly for use in Australia and New Zealand, but they have also been exported to Japan, New Guinea, Thailand, India and the United Kingdom. The average cost of a source is about $15,000 and it has a useful working life of about four years.

Other radioisotopes of gold, iridium and tantalum are being used for radiotherapy involving insertion of the radioisotope material into the actual tumour and allowing it to irradiate the diseased tissue from inside. In the case of gold, small beads are used and these are usually injected and left in position as they lose their radioactivity in a few days and cause no harm otherwise. Other radioisotope materials are made up into strings of beads or wires and inserted for fixed periods of time into small tubes strategically placed in the tumour.

The radiation from radioisotopes is no more and no less effective for radiotherapy than that which can be obtained from X-ray machines and linear accelerators. The main contribution that radioisotopes have made is to provide less expensive radiation and radiation sources in forms which can be used more conveniently, particularly for internal therapeutic applications.

USE OF HIGH ENERGY RADIATION TO PRESERVE FOOD

In view of the problems of food supply in some parts of the world, there is considerable interest in methods of improving the storage life of foodstuffs. Any such method would contribute to world-wide efforts to safeguard the increased supplies of food produced by improvements in agriculture and fisheries.

The potential value of preserving food by irradiation to prevent microbial and insect damage and hence slow the processes of deterioration, has been recognised for many years and a large volume of information has been gathered on the effectiveness of such a procedure. Such treatment would involve appropriate packaging of the food to exclude oxygen and airborne micro-organisms and exposing the package to a specified dose of radiation. However, the practical introduction of food irradiation has awaited widespread recognition that irradiated food is completely safe for human consumption.

The experimental data available on the wholesomeness of various food commodities has been submitted to expert evaluation by the International Project in the Field of Food Irradiation, which commenced in 1971 and is sponsored by the Food and Agriculture Organisation, and the International Atomic Energy Agency. The data represent very thorough studies of the wholesomeness of irradiated foods including their nutritional value, microbiology, any chemicals produced and any potential toxicological effects. Five food items (namely, potatoes, wheat, chicken, papaw and strawberries) have been found to be unconditionally safe for human consumption and three others (rice, fish and onions) were given provisional approval.

It is expected that recognition of the safety of irradiated foods will lead to the use of irradiation for preservation, when this is practical, and to international trade with irradiated foods, thereby helping reduce the problems of world food supply.

DETECTION AND DESTRUCTION OF TERMITE INFESTATION

Termites or "white ants" form extensive colonies underground with active centres connected by extensive galleries. In nature, termites have a very important function in that they rapidly consume any dead timber left on or in the ground and effectively remove the roots of dead trees so that more may grow. However, civilised man uses dead trees i.e. timber, extensively to build his dwellings and other structures which are in contact with the ground. Unless special precautions are taken these are subject to attack by termites and the destructiveness of these insects is very well known. One of the main problems in dealing with termites arises from the fact that their colonies are underground and as they attack through the ground are seldom detected before damage has occurred.

The AAEC has developed a special bait which is preferred to other food by termites. When a radioactive substance is added to this bait and the bait placed where termites are present, the peculiar communal feeding habits of the insect involving transfer of food from the gut of one termite to others ensure that the radioactive material is very rapidly spread through the whole colony. By virtue of the fact that radiation from radioactive isotopes can pass very easily through solid material it is possible to trace the extent of the whole termite colony from above ground by sensitive radiation detectors. One termite colony in the Northern Territory was found to extend over an area of $1\frac{1}{2}$ hectares (about 4 acres) and to contain over 10 million insects. The radioactive bait was spread over the whole colony in less than 72 hours. The radioisotope used has a very short life time and once it has done its work it becomes harmless and disappears, although at no time is sufficient used to cause any danger. Use of this technique has provided much new information on the behaviour of termites.

Considerable success has been obtained in exterminating termite colonies by placing a slow acting insecticide instead of the radioisotope in the bait. Appropriately placed poison baits have been shown to destroy termite colonies containing about 10 million insects completely within 3 or 4 days.

Detection of Termite Damage in Railway Sleepers

A large iron ore mining company operates a very busy railway carrying its ore from the mine to Port Hedland in Western Australia. The line is over 250 miles long and contains nearly a million jarrah sleepers. Jarrah sleepers were used because this timber is generally regarded as resistant to termites. However, the very ravenous termites which live in the northern part of Western Australia have caused extensive damage to these sleepers. Because the termites enter the timber from the ground the damage is not easily seen. A sleeper can look quite intact but be a hollow shell completely eaten out by the termites. Such damage to sleepers may cause derailment of an ore train.

Under contract the AAEC developed a radioisotope instrument for detecting termite damage in sleepers. This instrument is mounted on a trolley which is moved over the railway line at about 8 kilometres an hour continually sending four radiation beams from two radioisotope sources down into the railway sleepers. Solid sleepers strongly reflect the radiation beam whereas the damaged or hollow ones reflect less radiation so that sleepers which are significantly damaged by the termites can be readily detected.

RADIOISOTOPE GAUGING

The intensity of the radiation from radioisotopes is attenuated, or reduced, in intensity as it passes through solid materials. One form of radiation known as beta rays is completely attenuated by about 1/8th of an inch of steel or even less of the heavier metal lead. On the other hand, radioisotope gamma rays which are very much like X-rays but more penetrating, need something like a foot of steel or three feet of concrete to absorb them effectively. It is well known that heavy metals and concrete are used for radioactive shielding.

The attenuation of radiation by solid materials is also used for gauging purposes. Using beta rays, the thickness of sheet materials can be measured during production. A radioisotope source is placed on one side of the material and a detector on the other - the intensity of the radiation which reaches the detector is an indication of the thickness of the material passing through. Such gauges are used universally now for on-line control of the thickness of materials which are made in a sheet form such as paper, plastic sheet, metal foils, metal sheets, composite sheets, etc.

The attenuation of radiation may also be used for detecting incomplete filling of containers such as drink cans. As the cans pass along a production line a beam of radiation is shot across the top of the can. If the can is properly filled no radiation passes through and it is registered as acceptable. If it is not properly filled radiation reaches the detector and the can is automatically rejected from the line. A similar principle is used in controlling and regulating ore and coal hoppers.

These are only a few examples of the many uses in which this radiation attenuation principle is used for improving the quality of our products of modern civilisation.

RADIOGRAPHY WITH RADIOISOTOPES AND NEUTRON BEAMS

Radioisotope sources are now used extensively in industry for X-ray type examination of welds, castings and other metal products to detect defects which may cause failure or deterioration of the article during use. The penetrating power of gamma rays makes them ideally suited for industrial radiography and radioisotope sources have the additional advantage that they are small, portable and need no power supply for their operation. For this reason they are used extensively in field work, particularly for examination of welds in overland pipelines, such as those used for transporting oil and natural gas.

The two most frequently used radioisotopes are cobalt 60 and iridium 192 which are made by irradiating normal cobalt or iridium metal with neutrons in a reactor. Cobalt 60 has a very powerful gamma ray and is very useful for examining heavy metal structures up to 8 inches thick. Iridium radiation is somewhat softer and is used for examination of thinner metal sections and light alloys. Iridium 192 is particularly valuable for the examination of the integrity of the turbine systems of jet engines. The radioisotope source is inserted down the hollow centre of the shaft of the engine and by putting X-ray film around the outside one can get a simultaneous X-ray or radiograph of all the turbine blades with minimum dismantling of the engine.

Neutron beams from reactors are now becoming very useful for examining industrial components for the integrity of hydrogen-containing materials. Unlike X-rays, which are absorbed to some extent by all materials and hence variations in transmission may indicate hollow defects or regions of different density, neutrons pass through many dense materials such as lead, but are scattered or absorbed strongly by light materials such as hydrogen or boron. An example of how this can be used to advantage is in a routine examination which is carried out at Lucas Heights for Qantas using the reactor Moata as a source of neutrons. The emergency doors of the Boeing 747 plane have explosively operated thrusters which open the doors on the press of a button in the case of an emergency. These thrusters have a small explosive charge in them and also contain rubber sealing rings and a hydraulic fluid. After assembly and during use, the presence and position of the explosive, the sealing rings and the presence of hydraulic fluid must be checked and the only way that these can be 'seen' inside the metal assembly is by radiography with neutrons. The 'X-ray' picture obtained with neutrons shows very clearly the 'neutron shadows' thrown up by the explosive, the rings and hydraulic fluid which contain a high proportion of hydrogen.

ACTIVATION ANALYSIS

Neutron activation analysis, often referred to as NAA, is a method of analysing materials to determine the concentrations of certain elements present. In some cases, NAA has advantages over all other methods of analysis. Such advantages include speed of analysis, simultaneous measurement of several elements, and the ability to measure very small concentrations, typically less than one part per million. The latter aspect enables neutron activation analysis to be used on very small samples which it would not be possible to analyse by other techniques.

The method involves bombarding a sample of the material with neutrons which react with the nuclei of atoms of some elements to produce excited or radioactive atoms. Only the atoms of elements which react readily with neutrons are affected. The radioactive atoms formed from the different elements emit radiation which is characteristic of them. Hence, the concentration of certain elements in the material may be determined simply by measuring or counting the characteristic radiations at an appropriate time following irradiation.

A particular application of neutron activation analysis is the identification of the source of an object by measuring the relative amounts of trace elements present. Most materials contain elements in trace amounts which are characteristic of the source of the material. For this reason NAA is used extensively in connection with police investigations and two officers of the Commonwealth Police are attached full-time at Lucas Heights for such work. Their work includes examination of drug samples to determine the source of supply, analysis of hair for identification purposes (i.e. comparison of hair found at the scene of a crime with that of suspects) and in cases of suspected arsenic poisoning, and examination of swabs from suspect's hands for gun shot residues. The latter analysis may indicate whether or not a person has fired a gun recently and was used to prove that an incident in which a Sydney policeman was killed during a struggle with a youth, was an accident and not manslaughter as indicated by the circumstances which suggested that the youth had the gun at the time of the shot. NAA evidence showed conclusively that only the policeman had held the gun when it was fired.

Similar uses of NAA include determining the source of origin of artefacts in archaeological investigations and examining chips of paint from paintings claimed to be 'old masters' to establish whether the paint has an appropriate composition. However, the main applications are for rapid, routine chemical analysis for some specific elements. For example, a very rapid method for analysis of uranium in ores and other materials has been established at Lucas Heights and this is provided as a service to other organisations. The samples are inserted into the Moata reactor, withdrawn, the delayed neutron activity counted and recorded on tape, all in less than two minutes. Subsequently the information on the tape is processed using the computer to calculate the uranium content and print out a results sheet for the client. Analysis for uranium by normal laboratory methods would take about 30 minutes. Organisations involved in uranium prospecting have made extensive use of the service and in 1976 more than 11,000 samples were analysed.

Protons, the positive nuclei of hydrogen atoms, emitted at very high speeds from an accelerator, can also be used for activation analysis.

Such protons interact with some elements and cause emission of characteristic radiations which can be used to identify and measure traces of these elements in materials. Trace analysis of obsidian daggers and other artefacts from the Pacific Islands has been used to identify the particular source of obsidian from which they were made and this has given archaeologists some indications of trade patterns in the islands some hundreds of years ago.

The application of these methods of analysis requires access to a suitable source of neutrons or high energy protons. In Australia, the only appropriate sources of neutrons are the reactors HIFAR and Moata at the AAEC Research Establishment. The AAEC facilities and expertise are made available to various Commonwealth and State Government Departments (such as CSIRO, the Commonwealth Police and the Bureau of Mineral Resources), University workers and commercial organisations for solution of specific problems.

ON-STREAM ANALYSIS WITH RADIOISOTOPES IN THE MINERAL INDUSTRY

In the processing of many mineral ores to extract the valuable commercial metals they contain such as lead, zinc, copper and tin, the ore is passed through an enrichment process which separates material which is rich in the metal of interest and rejects the remainder. A technique frequently used for achieving this separation is 'flotation'. In this the ore is finely ground and made into a slurry with water and the slurry is treated with a small quantity of a special chemical which affects the surface properties of the particles. Air is passed through a slurry in the form of millions of small bubbles - the bubbles stick to the particles of valuable mineral and float them to the top where they are collected and the waste ore passes on.

In such a process it is most important to know exactly the metal content of the feed and the product streams otherwise the effectiveness of the ore treatment is not known. Ineffective separation is uneconomic and wasteful. Until several years ago control of the process was achieved by taking samples from time to time, rushing them to a laboratory, analysing them as quickly as possible and sending back the results to the plant operator. It is easy to see that this involved substantial delays making effective control impossible. Too often the results simply showed what had happened, not what was happening.

The AAEC has been working on radioisotope techniques for automatic analysis in such conditions and after some 10-12 years research has developed equipment in which electronic signals from probes, containing certain radioisotopes, inserted in the slurry streams of mineral plants are used to calculate the percentage of the metal of interest in the ore stream. The system can be applied to most metals of commercial interest. The system works by analysing the way in which the metal in the slurry influences, in quite a subtle way, the radiation emitted by the radioisotope source in the detector probes. The electronic signals are processed by a computer which provides the plant operator with an immediate digital display of the metal concentration.

The Commission's research and development in this field extended to the actual testing of prototype systems in mineral plants in cooperation with the Australian Mineral Development Laboratories and Australian Mineral Industries Research Association. Subsequently, the technique was licensed to Philips Industries Holdings Limited for marketing and exploitation on a world wide basis. A large proportion of the mineral processing plants in Australia now use these systems for analytical control, and export sales are commencing.

This equipment is a unique development of Australian atomic energy research and the workers involved are now recognised as international authorities on this type of radioisotope application. The system of analysis was awarded the 1973 Prince Philip Prize for Australian Design, an annual award initiated by the Industrial Design Council of Australia.

BULK ANALYSIS OF COPPER AND NICKEL ORES

Commission research on the effects that the elements copper and nickel have on scattering the gamma radiation emitted from the radioisotopes zinc 65 and cobalt 60 respectively, has resulted in the development of analysers for measuring accurately the copper or nickel content of bulk quantities of ores (typically 20 kilograms). Such analysers have the great advantages that they can be used on the spot rather than in a remote chemical laboratory and the method is rapid. An analysis can be completed in about 5 minutes, so that the results are available for process control purposes. Also, a minimum of sample preparation is required. All the operator has to do is to crush a few kilograms of ore to a particle size of about 25 millimetres diameter and load it into a hopper, or in the case of borehole cores from diamond drill exploration holes from prospecting or surveys of known deposits, to stack the cores on a rack which is placed on top of the analyser. Because of the large sample size handled, the errors associated with selecting representative samples of ore for analysis are greatly reduced.

Although the effect on the scattered radiation is only small, it can be measured readily by modern radiation analysis equipment. The electronic signal obtained is converted by simple computer operations into the percentage of metal in the ore, which is presented to the operator as a digital display or recorded as a printout.

At present a prototype unit is being used for routine analysis of copper ores and borehole cores at a large mine where it has gained ready acceptance by the geologists responsible for its operation. Copper assays are obtained more quickly and at lower cost than is possible by conventional methods.

The Commission holds patents for the method in all major countries and has started negotiations with commercial organisations for world wide manufacture and distribution.

APPLICATION OF NUCLEAR TECHNIQUES OF ANALYSIS TO THE COAL INDUSTRY

A radioisotope technique is being developed for measuring the level of combustible volatile matter in coalmine roadway dusts to reduce the possibility of coal dust explosions occurring and hence to increase the safety aspects of coal mining. The New South Wales Coal Mines Regulations Act requires that coal mine roadways be 'dusted' with stone dust, generally finely ground limestone, when the combustible volatile matter in roadway dusts exceeds a specified level. The Department of Mines regularly collects dust samples from coal mine roadways for analysis in the laboratory. However, present methods for determining combustible volatile matter involve chemical techniques and hence appreciable delays between sampling and availability of results. The Department of Mines approached the Commission for help in the development of a simple alternative method which was rapid, inexpensive and could be used underground. A technique depending on backscatter of X-rays from the dust sample has been developed. The Department of Mines is now conducting an extensive test of the technique after which it is proposed to design portable equipment for routine use.

On-line analysis of coal for ash content (non-combustible matter such as rock, clay), moisture and energy content is important in many industries and potential savings to Australia of millions of dollars per year could result from better control of coal quality. Continuous determination of coal quality (on a conveyor belt for example) is required to control cleaning operations during coal processing and in blending operations in industries using coal such as electric power generation, and the steel and chemical industries.

Large savings may be made in coal washeries: Australian mining companies export coal worth several hundred million dollars per year and penalties are paid when the coal has an ash content greater than a specified value, typically 8 per cent by weight. Better quality control could result in savings of millions of dollars per year. Similarly, the use of low ash content coal during peak load conditions at a coal-fired power station could result in at least a 10 per cent increase in power output over that available at present due to variable and unknown ash content.

Various radioisotope techniques for determining ash content in coal have been developed overseas but all have limitations so that their use is not widespread. The AAEC is developing a new technique which overcomes many of these limitations. Further laboratory and field investigations are being carried out to prove the technique, particularly for conveyor belt applications.

STUDY OF WATER RESOURCES

Natural water on the surface of the earth and that which falls as rain or snow contains minute traces of radioisotopes. The main radioisotopes of interest in the study of water resources are those of hydrogen and carbon which are formed when cosmic rays from outer space interact with water vapour and nitrogen in the air. This maintains them at constant but very small concentrations in water on the surface of the earth.

Surface water frequently seeps underground into porous rocks and sand in what is known as an aquifer, and this groundwater is an important water resource in many parts of the country. The Great Artesian Basin is the largest and probably the best known underground water resource in Australia, although there are dozens of small aquifers being used for domestic and irrigation water supplies.

The fact that all water originally contained minute quantities of radioisotopes of hydrogen and carbon enables us to measure its age i.e. the time that has elapsed since it went underground, its rate of flow and recharge and indirectly, the total quantity of groundwater in any particular area. After water goes underground the radioisotopes are no longer replenished from the cosmic rays and they decay away. The radioisotope of hydrogen (tritium) loses half its activity in about 12 years and that of carbon in about 5½ thousand years. Thus, if we measure the minute amounts of these radioisotopes in water taken from various bores in the aquifer we can determine the "age" of each sample and from this, by careful choice of the position of the bore holes, derive the rate and direction of flow.

The AAEC has established laboratories for making the very precise measurements necessary and in cooperation with a number of water resource authorities in Australia has extensively investigated some groundwater resources. These include the Burdekin Delta, the Mereenie Sandstone Aquifer which supplies Alice Springs, the water supply for the Ayers Rock area, the Namoi Valley groundwater and in a very large experiment, the Great Artesian Basin. An interesting fact about the Great Artesian Basin is that water which is found at the south western extremity entered the Basin in central Queensland about a half a million years ago and has been travelling in a south westerly direction ever since at the rate of a few metres per year.

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