The atomic nucleus: Nuclear technology

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The two most obvious applications of nuclear physics have done the most to give the word a bad name: producing energy via the process of nuclear fission and facilitating mass destruction through nuclear bombs. But while the world debates to what extent it wants - or needs - nuclear power, the unique properties of atomic nuclei also impinge on our lives in less controversial ways

NUCLIDE	DECAY MODE	HALF-LIFE	EXAMPLE USE
carbon-11	β+	20 minutes	PET scans
fluorine-18	β+	110 minutes	PET scans
krypton-81m	γ	13 seconds	Imaging lung function
strontium-89	β–	51 days	Bone cancer therapy
zirconium-89	β+	78 hours	PET scans
technetium-99m	γ	6 hours	Imaging various organs
indium-111	γ, EC	2.8 days	Blood labelling
iodine-123	γ, EC	13 hours	Thyroid studies
iodine-131	β– γ	8 days	Thyroid cancer therapy
thallium-201	γ, EC	3 days	Tumour and heart imaging

β = beta, γ = gamma, EC = electron capture © NewScientist

Enlarge image

Energy hopes

Not least since a tsunami inundated the Fukushima reactors in Japan, power generation through nuclear fission is controversial. For all its faults, though, it is still considered by many to be one of the few reliable and constant sources of low-carbon power.

The alternative, harnessing the power of nuclear fusion, could go some way towards squaring the circle. A huge international effort is now under way in Cadarache, in the south of France, to do just that. The International Thermonuclear Experimental Reactor (ITER), due to come on stream in 2019, uses magnetic confinement of a hot ionised gas (plasma) in an attempt to kick-start a tame version of the fusion processes that go on inside the sun. Meanwhile, the National Ignition Facility (NIF) in Livermore, California, aims to ignite fusion in a plasma using "inertial" confinement after heating and compression with giant lasers. Measurements are now getting under way.

Nuclear fusion has a chequered history, and it remains to be seen whether such projects fulfil their promises. It is in our and the planet's interest that they do.

Speed dating

The fact that different nuclei decay at different rates makes some of them tremendously useful in determining the age of various objects.

A familiar example is the radiocarbon dating of organic materials. Carbon consists overwhelmingly of the stable isotope carbon-12, but living things contain a small amount of carbon-14. This isotope, with a half-life of 5730 years, is made at a steady rate in Earth's atmosphere in cosmic-ray collisions. It is incorporated into plants via photosynthesis and then into animals when they eat those plants.

As soon as the organism dies, this uptake stops. While the carbon-12 remains unchanged, the carbon-14 gradually decays and is not replaced. Thus, if you measure the ratio of carbon-14 to carbon-12, you get a measure of the time since death.

Performing radiocarbon dating used to require large samples because there are, even initially, only a small number of carbon-14 nuclei, and those that are there don't decay very rapidly. A more sensitive technique, which only requires tiny (milligram) samples, is accelerator mass spectrometry. The decay itself is not measured; instead, an energetic carbon beam is produced from the sample via an accelerator, with magnets and radiation detectors distinguishing between carbon-14 and carbon-12. This technique was used in 1989 to date a tiny piece of the Turin Shroud, reputed to have been used to wrap the body of Jesus while lying in his tomb. It showed that the cloth was much more recent.

Other dating techniques use different nuclides according to their half-lives. The decay of particularly long-lived nuclides, for example, is the basis of uranium-lead, potassium-argon, rubidium-strontium and uranium-thorium dating, used to assess the ages of different types of rock.

Resonant images

The phenomenon of nuclear magnetic resonance is used in an imaging technology with particularly wide application. Nucleons within nuclei act as tiny magnets, which have a preferred orientation in an externally applied magnetic field. The flipping of these magnets once aligned using an external pulse produces radio-frequency radiation that can be used to construct a detailed image of certain materials.

This is familiar from medicine as the magnetic resonance imaging (MRI) scan that is particularly effective in producing pictures of soft tissues in the body. But it has other uses, which are as diverse as measuring water uptake in trees and watching paint dry to ascertain mixes with optimal properties.

Nuclear medicine

Many medical diagnoses and treatments use radioactive isotopes. The most popular diagnostic nuclide, often used to locate bone problems, is the gamma-ray emitting isomer technetium-99m.

Technetium is taken up by growing bone, concentrating in areas of abnormal growth such as arthritic joints. The isomer has a half-life of only 6 hours - long enough to get a good picture in a surrounding gamma camera, but short enough that you don't get too much unwanted radiation. A recent global shortage of technetium, brought about by problems at two reactors in Canada and the Netherlands that together produced two-thirds of the world's supply, illustrated how ubiquitous and accepted this procedure had become.

Many other nuclides are used in medicine (see table). Those that decay through beta-plus emission are particularly prized for imaging: the emitted positron quickly annihilates with an electron in the surrounding material, producing two gamma rays that can be traced back to give the precise location of the emitter. This is the basis of the technique of positron emission tomography (PET) scanning.

Meanwhile, energetic beams of protons, or nuclei such as carbon, are increasingly used as a treatment for cancer with more localised effects than conventional X-ray radiotherapy. This can be especially suitable for the treatment of deep-seated brain tumours. A dedicated ion-beam treatment facility has recently begun operation at the University Clinic in Heidelberg, Germany.

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