High intensity beams of short-lived nuclei will be an invaluable tool in physics, chemistry, materials science and the biosciences.

Exotic nuclear beams
During the past 70 years, physicists have developed ever more sophisticated machines for accelerating beams of subatomic particles such as electrons and nuclei. These are species which are generally stable and do not spontaneously disintegrate into other particles. Now, a new generation of accelerators is under construction designed to produce intense beams of a wide range of less stable, radioactive nuclei. Such beams can be used not only to explore the structure of exotic nuclei never made before but also as an extremely useful resource in industry, medicine and the environment.

Extreme nuclei

Atomic nuclei, which make up most of the matter we can see in the Universe, consist of protons and neutrons in many combinations. The 283 stable or long-lived nuclear species that exist are, however, only a fraction of a possible 7000 that could be created with radioactive beams. Very little is known about most of these nuclei so the possibility of making them is very exciting. Certainly some of them possess unusual structures and unexpected properties.

One type recently discovered are neutron-rich species which contain a mane of neutrons or an extended neutron halo surrounding a dense neutron-proton core; another group are some curious nuclei that remain trapped in a high-energy state for a long period of time (see Box on spin traps). Beams of exotic, less stable nuclear will allow physicists to extend the use of positron imaging techniques in studies of, for example, catalysts and biological samples.

Medical applications

One established imaging technique which will gain from a radioactive beam facility is positron emission tomography (PET), in which positrons emitted by radionuclides reveal their locations and nature of their surroundings. It is easy to see that with the broad range of atomic and energies obtainable with radioactive beams, such techniques could be invaluable in studying technologically important magnetic and semiconductor materials, as well as wear and tear in engineering parts.

The production of radioactive beams also generates positrons (positively-charged electrons) whose energies can be controlled within a wide range. Positrons are often used to investigate surfaces, interfaces and thin films. When they encounter electrons, they annihilate to release a burst of characteristic gamma-rays which can be detected. An intense pulsed positron beam will enable the introduction of novel spectroscopic techniques previously inaccessible, and also

Beams of short-lived nuclei and their applications

Silicon is used in electronic circuits, but it is important to know where the silicon atoms end up in the crystal lattice. The images compare simulations and experiments for this process.

Radio-isotopes are themselves already used extensively in medicine as tracers, diagnostic tools and in cancer treatments. Radio-isotope technology will make available many more radionuclides for specific therapies than are currently on the market. For example, radio-lanthanides such as samarium-153 could be used in cancer therapy. When these isotopes are combined with compounds that selectively carry them to the tumour site, the radiation they emit when their decay kills the cells. Another radio-pharmaceutical, gallium-67, is often used to image fast-growing soft tissue. However, the use of a shorter-lived isotope, gallium-73, would greatly reduce the radiation dose to the patient.

Dealing with nuclear waste

Beams of short-lived nuclei will have environmental benefits too.

Spin traps

Some unusual isotopes have recently been discovered which possess stable excited states with high angular momentum or spin. They cannot lose energy but remain trapped in their high-energy spin state and are thus dubbed ‘spin traps’.

The most remarkable spin trap is the naturally occurring isotope tantalum-180 which has a half-life of more than 100 trillion million years! Another spin trap, hafnium-181, has 30 times the energy of the tantalum trap and survives for 13 years. Similar species with even more energy are expected to be created with radioactive beams.

Such nuclei present an intriguing technological challenge: if a large number of these nuclei could be decelerated on command, they would offer nuclear energy on tap, perhaps in the form of a gamma-ray laser or as an energy storage device for space propulsion.

The energy amplifier

Physicists including the former director of CERN and Nobelist Carlo Rubbia have produced an alternative scheme for producing nuclear energy in which a beam of high-energy protons interacts with thorium to accelerate the proton beam – hence its name ‘The Energy Amplifier’.

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**Medical applications**

One established imaging technique that will gain from a radioactive beam facility is positron emission tomography (PET), in which positrons emitted by radionuclides reveal their positions and the nature of their surroundings. It is easy to see how the usefulness of PET will be greatly enhanced with radioactive beams, such techniques could be invaluable in studying the structure of the brain and heart. Radio-isotopes are themselves already used extensively in medicine as tracers, diagnostic tools and in cancer treatments. Radioactive beam technology will make available many more radionuclides for specific therapies than are currently on the market. For example, radio-lanthanides such as samarium-153 could be used in cancer therapy. When these isotopes are combined with compounds that selectively carry them to the tumour site, the radiotherapy that might then be initiated could alleviate some of the decay problems that currently limit the use of radioactive drugs.

**Dealing with nuclear waste**

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The energy produced is very much more than is needed to accelerate the proton beam—hence its name ‘Energy Amplifier’. Its advantage is that it is sub-critical and would result in less long-lived and toxic radioactive waste. The underlying technology could also be adapted to transmute waste products from conventional reactors, and is most likely to be used in this model first.

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