# PARTICLE ACCELERATORS **AND PEOPLE**

ACCELERATORS PRODUCE BEAMS OF SUBATOMIC PARTICLES AND CHARGED ATOMS THAT HELP MANAGE OUR **HEALTH** AND THE **ENVIRONMENT**. THEY ALSO PROVIDE A SIGNIFICANT TOOL FOR **MANUFACTURING INDUSTRY**, FOR SUSTAINING **GREENER, SAFER ENERGY**, AND FOR SECURING OUR **BORDERS** AND ENSURING **NATIONAL SECURITY**. THEY OFFER **ADVANCED INVESTIGATION METHODS** CONSIDERED ESSENTIAL IN MANY FIELDS OF **BASIC AND APPLIED SCIENCE**.

**INNOVATIVE TECHNICAL DEVELOPMENTS ARE IN PROGRESS OR ON THE HORIZON, IN EUROPE AND ELSEWHERE, AND WILL EXTEND THE PRACTICAL USES OF ACCELERATORS EVEN FURTHER FOR THE SOCIAL AND ECONOMIC BENEFIT OF ALL.**

EuCARD$^2$

**APPLICATIONS OF ACCELERATORS IN EUROPE**

# WHAT IS A PARTICLE ACCELERATOR AND WHAT DOES IT DO?

**A PARTICLE ACCELERATOR ACCELERATES ELECTRICALLY CHARGED SUBATOMIC AND ATOMIC PARTICLES SUCH AS PROTONS, ELECTRONS AND IONS (ATOMS THAT HAVE LOST ELECTRONS AND BECOME CHARGED), FOR A WIDE VARIETY OF APPLICATIONS.**

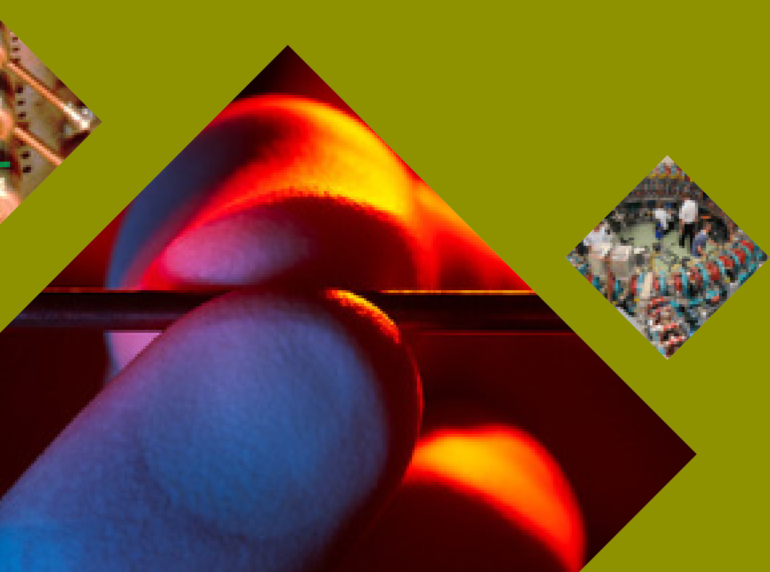
The most well-known application is in studies of the building blocks of the Universe, as carried out with the largest, highest-energy accelerator in the world, the Large Hadron Collider at the CERN laboratory in Geneva. However, smaller accelerators are to be found everywhere – in hospitals, in industry, research laboratories and even at border control facilities. Various types of accelerator can generate particle beams with a precisely defined energy for a particular application.

What is special about accelerated particle beams? They are 'precision instruments' that can effect a significant change in a material, depending on the particle type and its energy, with pinpoint accuracy in terms of location and penetration.

- Particle beams can cause chemical reactions or implant atoms in a target, and so are employed to make or improve materials. They can also break up biological material and so are used to kill microbes, or cancer cells.
- Proton beams, in particular, cause nuclear reactions in a material, and this is used to create radio-isotopes for use in medicine and scientific research. They could also be employed to destroy nuclear waste.
- Particle beams can generate intense X-rays and gamma-rays, and particles like neutrons, all of which are utilised in highly sophisticated analysis and imaging.

## HOW DOES AN ACCELERATOR WORK?

Charged particles are accelerated by a voltage, so the simplest accelerators rely on an electric field between two electrodes. Modern accelerators depend on devices that generate electric fields oscillating at radiofrequencies (called RF cavities), which enable particle beams to reach high energies. Magnets then control their direction and size.



## TYPES OF ACCELERATOR

There are two main types of accelerator: the linear accelerator, or linac, in which the particles shoot down a straight tube accelerated by RF cavities; and the circular accelerator such as a cyclotron or synchrotron, around which magnets bend and focus the beam. As the particles circulate, the RF cavities can accelerate them at every pass.

## NEW DEVELOPMENTS

Accelerators are generally large and expensive, so great efforts are being made to develop smaller, more cost-effective machines using powerful superconducting accelerator modules and magnets, and in more advanced configurations.

An exciting development, which would lead to 'table-top' accelerators, is the use of a powerful laser to generate a travelling plasma wave, along which particles can 'surf' to reach high energies in a small space. They can even be designed to operate on a silicon chip.

These concepts could revolutionise the use of accelerators, but they require further research.

APPLICATIONS OF ACCELERATORS
**IN EVERYDAY LIFE**

# ACCELERATORS AND...

## HEALTH

**ACCELERATORS PLAY A CRUCIAL AND GROWING ROLE IN INVESTIGATING AND TREATING WIDESPREAD DISEASES SUCH AS CANCER AND DEMENTIA.**

### RADIOTHERAPY

X-rays generated by accelerating an electron beam have been used to destroy tumour cells for many decades. Recent developments include the computer-controlled delivery of radiation doses whose shape matches that of the tumour, thus avoiding damaging healthy tissue.

Particle beams, in particular protons and light ions, can more effectively kill cancer cells because they slow down in tissues and deposit their energy in one place. By careful treatment planning, cancers in critical areas such as the head and neck can be treated safely.

**WHAT'S NEEDED:** SMALLER, LESS CUMBERSOME ACCELERATOR CONFIGURATIONS ARE NEEDED THAT CAN TREAT SEVERAL PATIENTS SIMULTANEOUSLY IN AS FEWER DOSES AS POSSIBLE.

### RADIO ISOTOPES

Forms of elements that are unstable (radio-isotopes) and emit radiation (particles or gamma-rays) are exploited for both imaging inside the body and therapy. Increasingly, these are created in accelerators.

Imaging relies on injecting a patient with a radio-isotope attached to a substance that localises in tissues of interest, and then detecting the radiation emitted so as to build up a computer image. Isotopes that emit single gamma-rays can be employed, but clearer images are obtained with isotopes emitting positrons (antimatter versions of electrons), which annihilate when they touch surrounding matter to release pairs of gamma-rays whose point of origin can then be mapped (positron emission tomography, PET).

Some isotopes emit radiation suitable for cancer therapy when injected attached to a carrier – for example, antibodies that 'recognise' specific cancer-tissue types and so can target cancer cells that have spread. Scientists are also studying new isotopes emitting both gamma-rays and particles that enable combined imaging and therapy.

**WHAT'S NEEDED:** RESEARCH IS GOING INTO MAKING NOVEL MEDICAL ISOTOPES FOR SPECIFIC APPLICATIONS, BUT THE AVAILABILITY OF ADVANCED ACCELERATOR DESIGNS IS ESSENTIAL FOR PROGRESS.

## SECURITY

**ACCELERATOR-GENERATED X-RAYS ARE A KEY TOOL IN THE FIGHT AGAINST SMUGGLING, PEOPLE TRAFFICKING AND TERRORISM, AND IN MAINTAINING EUROPE'S NUCLEAR DEFENCE.**

### BORDER SECURITY

Smuggling contraband or people has become a major concern in Europe. Accelerator-generated X-rays, gamma-rays and particles such as neutrons can penetrate containers and scan cargo, not only imaging the contents but also analysing their composition.

### COUNTER-TERRORISM

Similar accelerator technology can also help security teams identify and analyse suspected terrorist threats such as explosives and chemical, biological or radiological weapons.

**WHAT'S NEEDED:** A NEW GENERATION OF PORTABLE, RUGGED, LOW-COST ACCELERATOR SYSTEMS IS NEEDED THAT CAN ENSURE THE RAPID DELIVERY OF 3D IMAGES.

# INDUSTRY

**ACCELERATED BEAMS OF ELECTRONS (E-BEAMS) AND IONS PLAY HUGE ROLES IN MANUFACTURING, AS WELL AS IN ENVIRONMENTAL HEALTH PROTECTION AND CONSERVATION.**

Relatively low-energy beams have the advantage that they can be directed to cause a highly-controlled change at a selected location on, or just below, the surface of a material or object, without destroying their integrity. They also provide a significant toolbox of non-destructive techniques for analysing materials down to the atomic level.

## MANUFACTURING

E-beams can modify materials by causing chemical changes or by heating up the surface. Some of the many effects achieved include crosslinking polymers used in wires, cables and tyres, curing coatings, bonding delicate materials, welding and alloying metals, drilling or cutting surfaces to create nano-structured effects, or even changing the colour of gemstones.

In the electronics industry, e-beams and proton beams can etch circuits onto microchips, while ion beams can implant atoms into silicon to make the semiconductors that are the basis for this industry.

## HEALTH AND THE ENVIRONMENT

E-beams kill bacteria, so are used to sterilise medical implants and surgical implements, as well as seeds, spices and medical packaging. They also find application in cleaning up dirty water and sewage, and removing harmful sulfur and nitrogen oxides emitted from coal-fired power stations. A range of analytical methods based on ion beams can monitor air pollution such as dust.

## CULTURAL HERITAGE

While museums and libraries can use e-beams to kill pests damaging artefacts made from paper textiles and wood, one of the most interesting roles of ion beams is in analysing artworks and ancient artefacts to determine their composition, origin and age.

**WHAT'S NEEDED:** SMALLER, MORE PORTABLE ACCELERATORS ARE REQUIRED TO EXPLOIT FULLY THE BENEFITS OF ELECTRON AND ION BEAMS, TOGETHER WITH A BETTER UNDERSTANDING OF THEM AMONG POTENTIAL USERS AND THE PUBLIC.

# ENERGY

**ADVANCED NUCLEAR POWER IS AN ESSENTIAL COMPONENT OF FUTURE SUSTAINABLE ENERGY GENERATION. ACCELERATOR-BASED TECHNOLOGIES CAN CONTRIBUTE TO REDUCING ITS ENVIRONMENTAL IMPACT AND TO DEVELOPING INNOVATIVE SOLUTIONS.**

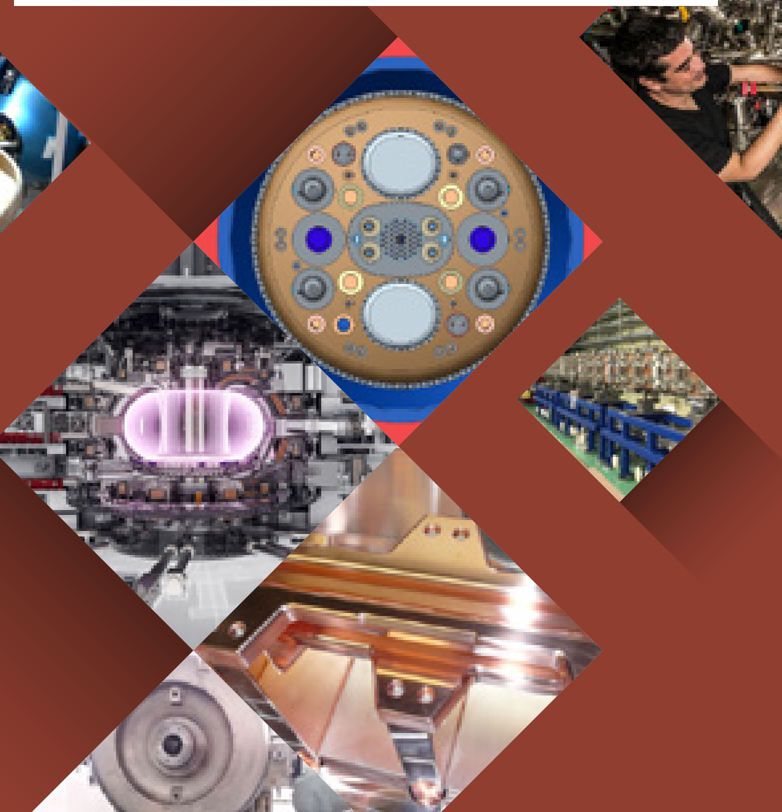
## DESTROYING LONG-LIVED RADIOACTIVE WASTE

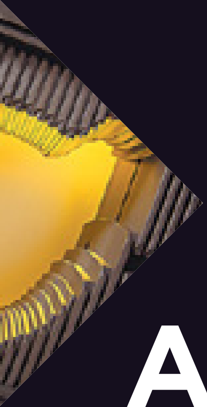
One of the main objections to nuclear energy based on uranium and plutonium fission is that it also creates very radio-toxic long-lived waste. However, a solution is now being studied, in which fast-moving neutrons created in a target by a proton accelerator cause further fission reactions in the waste, leading to shorter-lived products that are thus more manageable.

## MAKING NUCLEAR FUSION A REALITY

The nuclear fusion of hydrogen isotopes, deuterium and tritium, to generate helium, neutrons and energy offers the prospect of limitless, cheap, safe power, and the development of a fusion reactor is a major, long-term, global research effort. Neutral ion beams play a crucial role in these reactors. In addition, an important aspect of this work is to probe the damage to reactor materials caused by the fusion process. This is being studied using an accelerator-based source of neutrons to mimic reactor conditions.

**WHAT'S NEEDED:** BOTH NUCLEAR FISSION AND FUSION RESEARCH REQUIRE CONTINUED INVESTMENT IN POWERFUL PROTON ACCELERATORS AND THEIR TECHNOLOGY.





# ACCELERATORS AS 'MICROSCOPES'

**INTENSE RADIATION IN THE FORM OF X-RAYS OR NEUTRONS PROVIDES ONE OF MOST POWERFUL TOOLS FOR STUDYING MATTER. IT CAN REVEAL THE INNER WORKINGS OF MATERIALS AT THE LEVEL OF ATOMS AND MOLECULES.**

When a beam of X-rays or neutrons impinges on a material, they penetrate and are reflected, or scattered, off the arrays of the constituent atoms to give a scattering pattern characteristic of their arrangement. Any atomic and molecular motions, or energy changes, can be detected from changes in energy of the scattered beam.

X-ray and neutron scattering are employed to study a very wide variety of materials, from fuel-cell catalysts and photovoltaics, through advanced magnetic, electronic and engineering materials, to plastics and cleaning products. One of the most important uses is in biology and medicine to understand better the structure and behaviour of large molecules like DNA and proteins. Without these studies, many of the advances in medicine today would not have been possible.

X-rays and neutrons represent complementary tools because they interact with atoms slightly differently, so give different information.

The modern production of both X-rays and neutrons relies on large, powerful accelerators, which are installed in facilities that can be accessed by many user communities. Much research is now going into improved and novel designs to benefit scientific progress.

## X-RAY GENERATION

### SYNCHROTRON SOURCES

Large ring-shaped accelerators called synchrotrons, which accelerate electron beams, deliver extremely bright X-ray beams. As the electrons circulate around the ring, they emit the radiation at all wavelengths. The radiation is focused, and selected wavelengths are siphoned off to experimental areas.

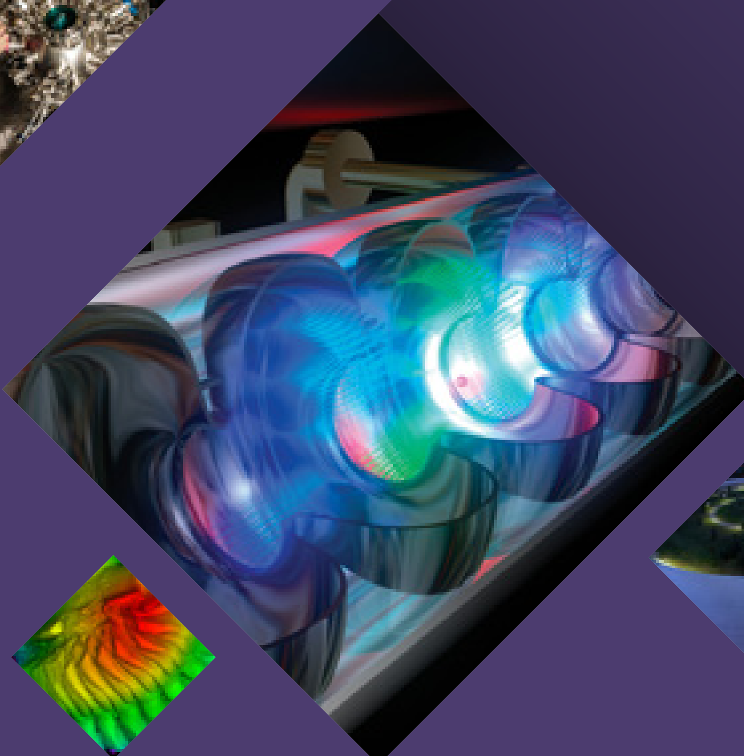
### FREE-ELECTRON LASERS

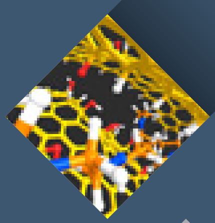
A more coherent X-ray source called a free electron laser is now being developed in which electrons are accelerated in a linac, and made to jiggle and bounce back and forth so that they emit bursts of very intense radiation.

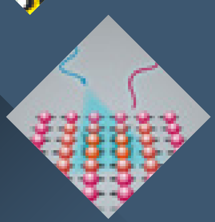
## NEUTRON SOURCES

Neutron beams are created in a dedicated reactor, or via an accelerator setup that provides protons to knock out neutrons from a target. The latter, so-called spallation source offers a more sustainable and environmentally friendly way of generating future neutron sources.

**WHAT'S NEEDED:** MORE COMPACT X-RAY SOURCES AND SPALLATION NEUTRON SOURCES – AND MORE OF THEM – ARE NEEDED TO MEET THE HIGH DEMAND.







# ACCELERATOR RESEARCH AND DEVELOPMENT IN EUROPE

**EUCARD-2 (EUROPEAN COORDINATED ACCELERATOR RESEARCH AND DEVELOPMENT) INTEGRATING ACTIVITY IS A PROGRAMME SUPPORTED BY THE EUROPEAN COMMISSION, UNDER FP7 (7TH FRAMEWORK PROGRAMME FOR RESEARCH AND TECHNOLOGICAL DEVELOPMENT), TO FOSTER AND DEVELOP PARTICLE-ACCELERATOR TECHNOLOGIES.**

Promoting the applications of accelerators is a priority, so a EUCARD-2 project was launched in June 2015 called Applications of Particle Accelerators in Europe (APAE), which aims to show how the accelerator technology, developed as a result of accelerator research, is of benefit to the wider community.

The APAE project aims to promote the development of novel accelerator technologies and to identify new applications in six sectors:

- **HEALTH** – accelerators produce particles, radiation and radioactive isotopes for use in cancer treatment, imaging and medical research.
- **INDUSTRY** – accelerators generate particle beams used to analyse and fabricate modern materials such as those used in electronics and engineering.
- **ENERGY** – accelerators can be employed to destroy radioactive nuclear waste and to research into new, safer forms of nuclear energy.
- **SECURITY** – accelerators generate radiation and particles used for screening operations in border security, counter-terrorism and nuclear security.
- **ANALYSIS WITH PHOTONS** – accelerators can be configured to emit extremely bright light (photons) used to probe the atomic or molecular structure and behaviour of materials that are important in the life sciences and in industry.
- **ANALYSIS WITH NEUTRONS** – accelerators can generate subatomic particles called neutrons, which are also employed to study matter in a complementary way to photons.

**For further information contact:**
**Maurizio Vretenar**, EuCARD-2 coordinator, (CERN)
Email: maurizio.vretenar@cern.ch

**Angeles Faus-Golfe**, APAE coordinator
(IFIC Valencia – LAL Orsay),
Email: fausgolf@lal.in2p3.fr

**Rob Edgecock** (U. Huddersfield – STFC)
Email: t.r.edgecock@hud.ac.uk
Website: http://apae.ific.uv.es/apae

The main APAE document, Applications of particle accelerators in Europe, is available at:
http://apae.ific.uv.es/apae

CAPACITIES

**EDITOR:** Nina Hall *nina@ninahall.org*
**DESIGN:** h2o-creative.com

## KEY AIMS FOR EUROPEAN R&D INTO APPLICATIONS OF PARTICLE ACCELERATORS

- More-compact accelerators using new configurations, superconducting components, and novel means of acceleration such as lasers.
- Simpler, cost-effective designs that are more efficient, robust and reliable, cheaper to run and more mobile.
- Further development of combined irradiation and imaging for the health and security sectors.
- Effective academia–industry interactions so that industry can benefit quickly from technical advances developed for ‘big science’.
- Improved student training to ensure the flow of a skilled workforce and knowledge-transfer to industries manufacturing and applying accelerator technology.
- Improved public understanding of accelerators and their science, with more accurate perceptions of any associated radiological risk.
- Improved R&D collaboration within the EU and at the level of the EU.