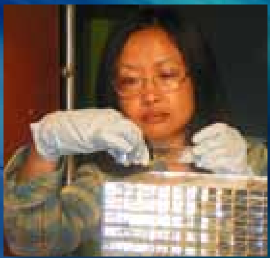
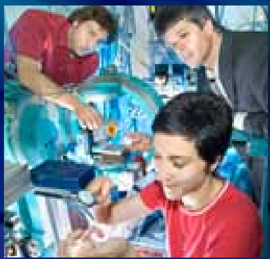







ACCELERATING INNOVATION

How nuclear physics benefits us all

U.S. DEPARTMENT OF ENERGY

Researchers at nuclear physics facilities — including at our national labs — make important contributions that benefit society in many ways.

Introduction

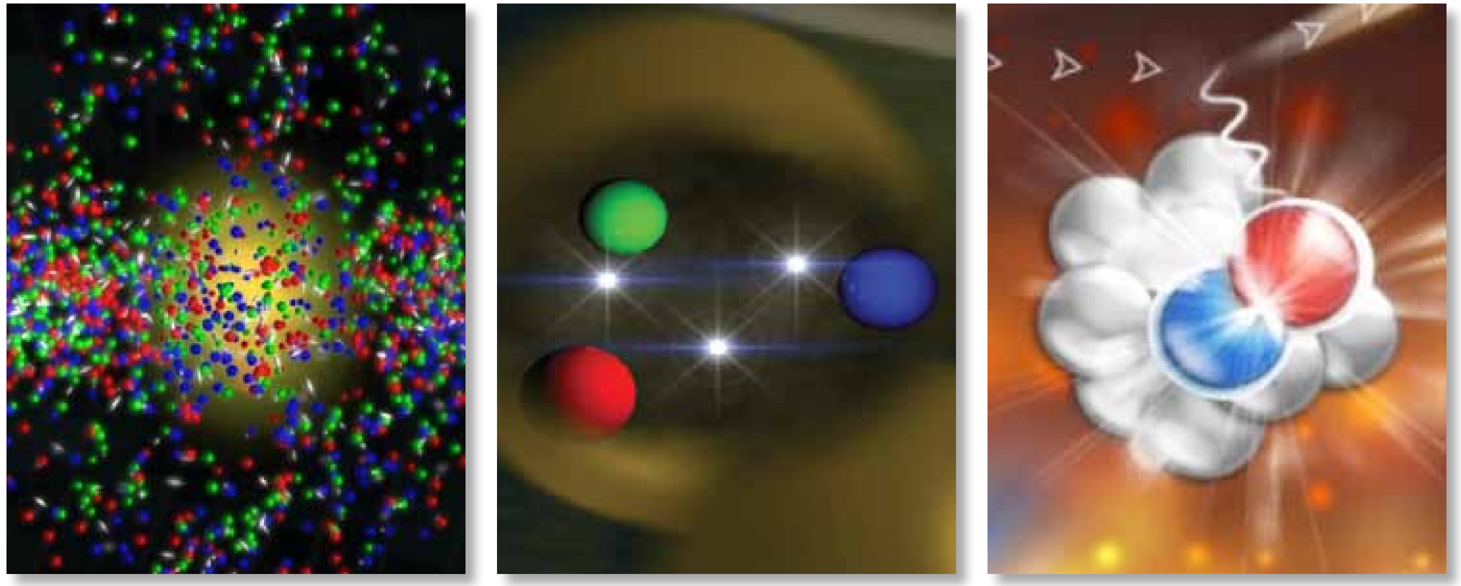
From fighting cancer to assuring food is safe to protecting our borders, nuclear physics impacts the lives of people around the globe every day.

In learning about the nucleus of the atom and the forces that govern it, scientists develop a depth of knowledge, techniques and remarkable research tools that can be used to develop a variety of often unexpected, practical applications.

These applications include devices and technologies for medical diagnostics and therapy, energy production and exploration, safety and national security, and for the analysis of materials and environmental contaminants.

Nuclear physics and its applications fuel our economic vitality, and make the world and our lives safer and healthier.

What is nuclear physics?



Nuclear physicists study the fundamental building blocks of matter, from quarks and gluons (left) to individual protons (center) and atomic nuclei (right).

Research in nuclear physics leads to benefits that are difficult to predict. If the past is an indication, the benefits to society will be many and life changing.

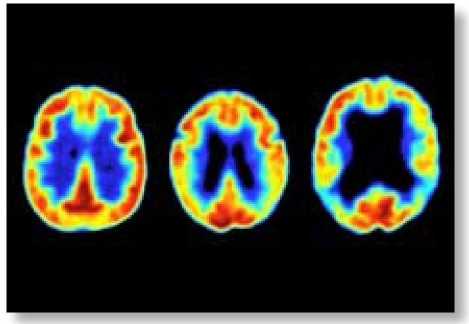
Nuclear physics is an important pursuit because the study of the nucleus of the atom is at the heart of our ability to understand the universe. It provides answers and expands our knowledge of both the infinitely small and the extremely large.

For instance, we have learned that the nucleus exists as a result of relatively simple interactions between subatomic particles known as quarks and gluons. And that these particles form a complex system of incredible richness and diversity that makes it possible for us, our world and our visible universe to exist. But there's still much to learn about these particles and the forces influencing them.

In pursuit of this knowledge, nuclear physicists probe nuclei with complex devices called accelerators, gather information from the probes with sophisticated detector systems, and record and analyze that information through advanced computing. They then share what they've learned – concepts, tools and techniques – with many others, including cosmologists and astronomers seeking to understand the origins and workings of the universe, and those studying complex systems and emergent phenomena in biology.

Pursuing this knowledge leads to benefits that are difficult to predict. Likewise, many outcomes and possible applications resulting from this pursuit cannot be imagined at this time. If the past is an indication, the benefits to society will be many and life changing.

Improving our health



PET scans reveal reduced brain activity in people with Alzheimer's disease (right) and cognitive impairment (center).

Advances in accelerator physics have led to more effective cancer-killing beams.

Bone scans locate cancerous growth by indicating increased uptake of radioactive Technetium (99mTc).

The link between medicine and nuclear physics research may be a surprise to many. Yet, for more than a century, the medical field has looked to nuclear physics for new discoveries and practical applications for finding the source of illness and improving treatment.

Today, nuclear medicine is an essential part of modern healthcare strategies, both for diagnosing and treating illnesses, particularly cancer and heart disease. Medical imaging techniques, notably single photon emission computed tomography (SPECT) and positron emission tomography (PET), have their roots in discoveries made by nuclear physicists. These technologies use radioisotopes and radiopharmaceuticals — chemicals "tagged" with radioactive elements that help doctors see inside the body and/or target particular cells — which also sprang from nuclear physics research.

More than 10,000 hospitals worldwide use these imaging techniques. In the U.S., there are some 18 million nuclear medicine procedures per year, and about 10 million in Europe, with use worldwide growing at more than 10 percent a year.

PET isotopes have helped reveal how addictive drugs affect the brain and are being explored as imaging agents to identify hypoxic (oxygen-deficient) tissue in patients following a heart attack or stroke. Organ-specific PET imagers have been developed that improve the sensitivity of detectors to certain types of tumors, resulting in earlier detection of disease and more effective treatments. Recently, doctors have begun using PET scans to reliably diagnose the presence of Alzheimer's disease in those with memory problems.

Other recent medical advances derived from nuclear physics include particle beam therapy for cancer treatment, which has evolved from pilot projects at nuclear accelerator facilities to dedicated operations at medical centers and to dual-purpose facilities for physics research and oncology. Particle beam therapies kill cancer cells more effectively than conventional radiation treatments. They use a range of particles — from electrons and nuclei (such as protons, helium and carbon) and pi-mesons, produced by an accelerator and transported by a system of magnets, to neutrons, produced by radioactive elements and special equipment or by accelerators.

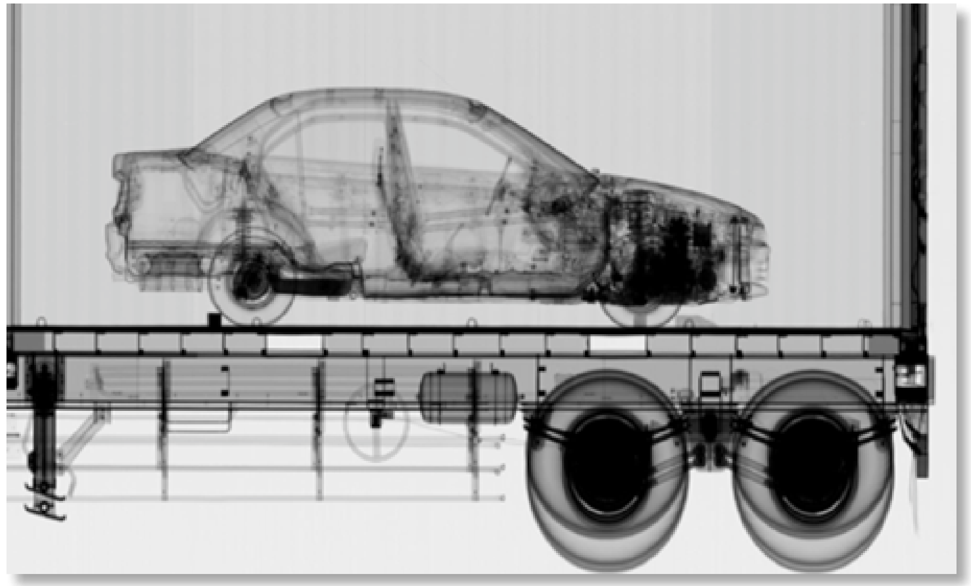
Other medical imaging techniques also have roots in nuclear physics research. These diagnostic techniques, including computed axial tomography (CAT) and magnetic resonance imaging (MRI), have a critical role in providing effective medical care.

Additionally, researchers are applying their knowledge and capabilities to help the medical field develop longer-lasting artificial hips. About 200,000 hip joint replacement surgeries are done each year, with a typical replacement hip lasting 10-20 years before wearing out. Nuclear physics researchers are helping to conduct wear studies to develop more durable materials.

Making the world safer

Techniques developed by nuclear physicists eliminate potential pathogens in our food supply.

Developing innovative detectors is crucial to identifying hazardous materials in shipping containers.



Nuclear physicists are developing new ways to screen cargo.

Nuclear scientists play an important role in deterring the use of nuclear weapons and dirty bombs by identifying the source of a potentially hazardous material.

To conduct their research, nuclear physicists develop detectors to identify, track and provide many other details about subatomic particles, such as those produced by particle accelerators. This capability has enabled nuclear scientists to contribute to a broad range of national security capabilities and applications.

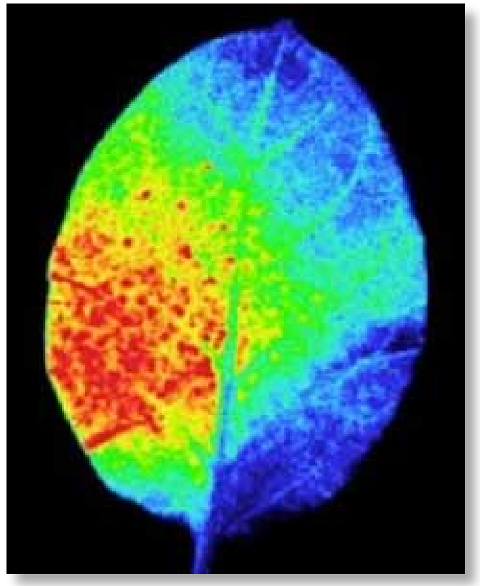
For instance, nuclear physicists are working to make air travel safer. When you travel by air today, you are restricted in the liquids you can bring. This is because current X-ray machines cannot distinguish between benign and hazardous liquids. Nuclear scientists are working to provide a better screening device.

Nuclear scientists play an important role in deterring the use of nuclear weapons and dirty bombs by identifying the source of a potentially hazardous material. These scientists use their knowledge to identify new detection signatures for nuclear materials or chemical explosives. Additionally, they support the work of assessing and certifying the safety and reliability of the U.S. nuclear stockpile.

Intercepting smuggled nuclear materials or other contraband at national borders is another concern. The Department of Homeland Security wants an infallible method for verifying that large shipping containers and trucks are safe, and to do it quickly without interrupting commerce. Nuclear resonance fluorescence (NRF) may provide a solution. It's a way of detecting the unique set of nuclear "fingerprints" produced when specific high-energy gamma rays are absorbed and re-emitted by certain materials.

Electricity, environment, archaeology...

Next-generation nuclear reactors will operate with increased safety and flexibility.



PET scans reveal how plants respond to rising CO_2.

Archaeologists used accelerator-based studies to more accurately date 12,000-year-old cave paintings.

As the nation prepares for a sustainable energy future, more attention is being focused on nuclear energy. For almost 60 years, nuclear energy has helped the U.S. meet its electricity needs, providing about 20 percent of our electric power. With growing demand for environmentally friendly, non-carbon-emitting technology, nuclear power is likely to have an even bigger future role.

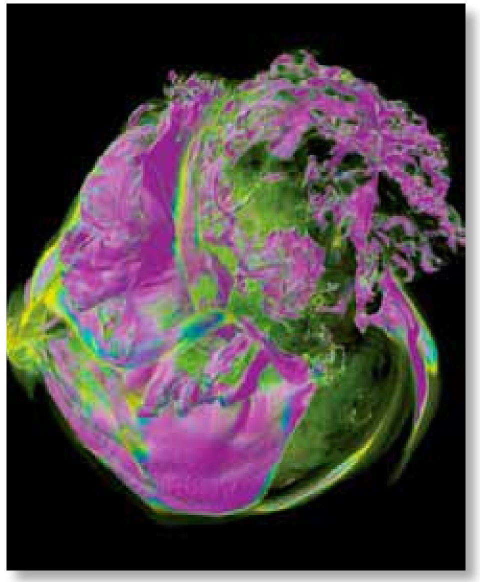
To reduce the potential of nuclear proliferation, scientists around the world are also exploring a method for using particle accelerators to create the fission that produces electricity, but with materials that do not create, as a by-product, bomb-grade material. So-called accelerator-driven systems (ADS) offer the possibility of producing electricity with increased safety and flexibility. Other research includes neutron beams and state-of-the-art detectors to improve our understanding of nuclear systems and constrain costs.

Scientists are also using tools of nuclear physics to explore the effects of rising carbon dioxide (CO_2) and improve the prospects for harnessing energy in the form of biofuels. For example, plant researchers are using positron emission tomography (PET) to track the movement of carbon and other nutrients through plants to understand how rising CO_2 affects plant physiology, and to learn how potential biofuel-producing plants can be optimized to take advantage of additional CO_2.

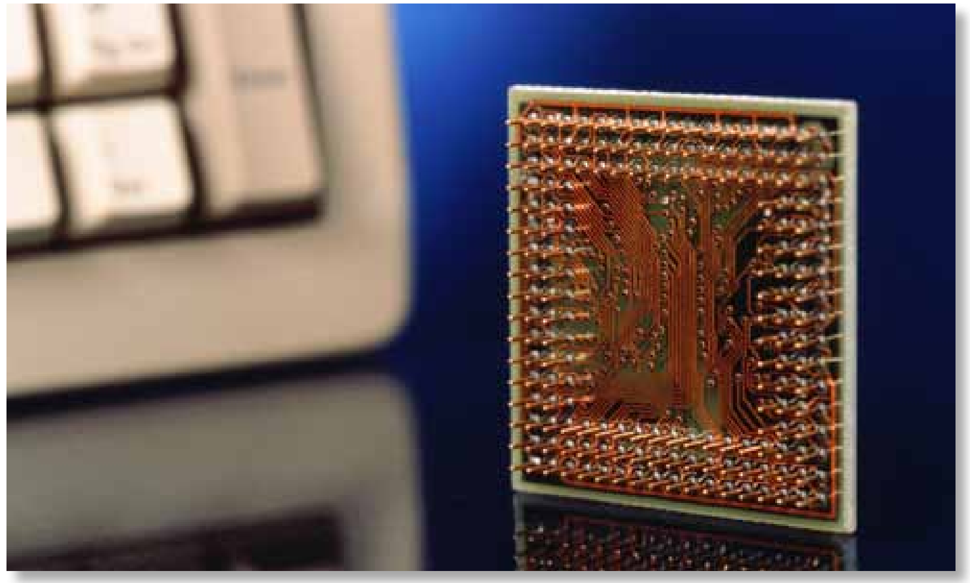
Even archaeologists benefit from nuclear physics techniques: At the Research Laboratory of the French Museums, located within the Louvre, archaeologists used accelerator-based studies to classify the paint recipes of 12,000-year-old cave paintings, leading to a more accurate chronology of the cave art.

Accelerator-driven nuclear energy systems offer the possibility of producing electricity with increased safety and flexibility.

Better computers



Nuclear physicists have used computational techniques to simulate what happens in an exploding supernova.



Nuclear physics has pushed the development of advanced computing power and led to innovative ways to test chips' reliability and stability.

...helping to build powerful machines with supercomputer-style processor speeds to collect and analyze data, but without the supercomputer-style price tag.

Nuclear physics research has stimulated the computer industry. In order to conduct experiments and to make theoretical predictions, nuclear physicists are pushing the envelope of high-performance computing. They are helping to build powerful machines with supercomputer-style processor speeds to collect and analyze data, but without the supercomputer-style price tag.

When major computer corporations wanted to build the fastest computer in the world, they turned to scientific users of massively parallel computers: the theorists trying to solve the equations of nuclear physics to better understand the evolution of the universe, supernovae explosions and gamma-ray bursts. The computational techniques used to address these complex physics problems are now applied to other complex problems, such as climate modeling and predicting protein structures.

Sophisticated computer simulation codes that were born in the basic physics research community also have become industry standards for modeling particle interactions in bulk materials, and in helping companies improve equipment prototyping and design.

Yet another application involves satellites, which depend on the reliability of advanced computer chips. These chips, whether in Earth orbit or on distant space missions, are constantly exposed to damaging cosmic rays. Using accelerators developed for nuclear physics research, specialists can test the chips' response to radiation before they are sent on space missions, allowing changes to be made to increase reliability.

Contributions to industry

The Cassini spacecraft gets power from plutonium, a nuclear isotope.

Atom-trapping lasers count a few atoms of an isotope to date ice for geological studies.

Radioisotopes developed, studied or produced by nuclear physicists have found their way into our homes and a variety of industries. To name a few:

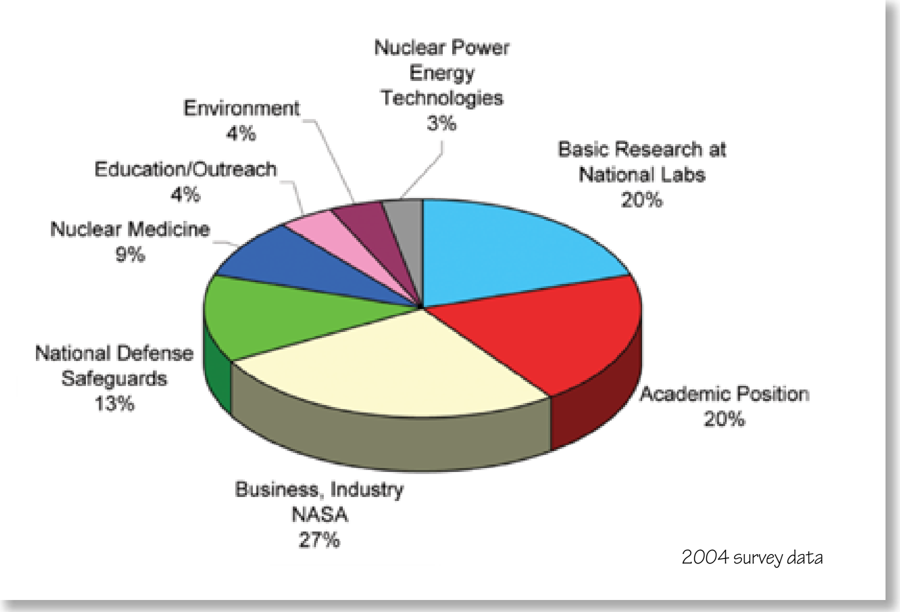
- Americium is used in smoke detectors you buy at the local hardware store, to ensure uniform thickness in rolling processes like paper production, and to help determine where oil wells should be drilled.
- Californium helps scan luggage for hidden explosives and gauge moisture content of soil in the road-construction and building industries.
- Cesium is used as a thickness gauge in steel production, and to measure and control the liquid flow in oil pipelines.
- Cobalt irradiation helps to sterilize surgical instruments and keep our food supply safe.
- Iridium is used to test the integrity of pipeline welds and also in irradiation of tumors.
- Thorium helps fluorescent lights last longer.
- Spacecraft benefit from isotopes such as plutonium, which supplies power needed especially when the spacecraft is far from the sun.

Refrigeration technologies first developed to operate superconducting particle accelerators, which must be kept super-cold, are now available for commercial use. NASA uses similar processes to replicate the super-cold conditions in space for equipment testing.

The ability to control and focus protons and the detector technology designed to monitor them have allowed researchers to develop an imaging technique that uses protons, rather than X-rays, for more penetrating power. Using proton radiography, researchers can therefore record more detailed information on the motions and densities of materials than was ever possible before. Other industrial uses for proton radiography include studying coolant flow in automobile engines and the pattern of energy dispersal from high explosives, as well as the capability to image components inside massive machinery.

Accelerators are also used to aid in the production of very small pore filters for applications such as water filtration, filtering of small molecules, proteins, and viruses. This material is also used as a substrate for tissue growth where nutrients can pass through the material to nourish the tissue but the pores are too small for the tissue to grow into.

Training the next generation of innovators



The pie chart above shows that many scientists who receive Ph.D.s in nuclear science go on to apply their knowledge working in professions outside the field after five to 10 years.

This educational pipeline further fuels our economy through work in fields as diverse as national security, medicine, energy generation, space exploration, and more.

The Office of Nuclear Physics within the Department of Energy's (DOE) Office of Science has a long and productive partnership with universities and provides education opportunities and support to university professors and students associated with its basic nuclear physics research.

More than 500 DOE-supported researchers have earned Ph.D.s over the past five years. These students get most of their hands-on experience, in both basic and applied areas, at national laboratories predominantly supported by DOE Nuclear Physics.

One-third of these highly educated people go on to work in government service or at national research labs, another third join science and technology industries, and the final third go on to educate and train the next generation of skilled workers and conduct research in academic environments. As the examples presented here attest, this educational pipeline further fuels our economy through work in fields as diverse as national security, medicine, energy generation, space exploration, and more.

Nuclear physics research facilities serve as training grounds for the next generation of scientists and engineers.

The Office of Nuclear Physics in the Department of Energy (DOE's) Office of Science supports the experimental and theoretical research needed to create a roadmap of matter that will help unlock the secrets of how the universe and everything in it is put together. This quest requires a broad approach to different, but related, scientific frontiers: improving our understanding of the building blocks of matter; discovering the origins of nuclei; and identifying the forces that transform matter. This research advances knowledge, technology, and skills that enhance national security, energy security and efficiency, environmental protection, health and safety, and a wide range of commercial enterprises, and helps to educate and train future scientists.

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For more information about DOE's role in nuclear physics research, go to http://www.science.doe.gov/np/index.html.