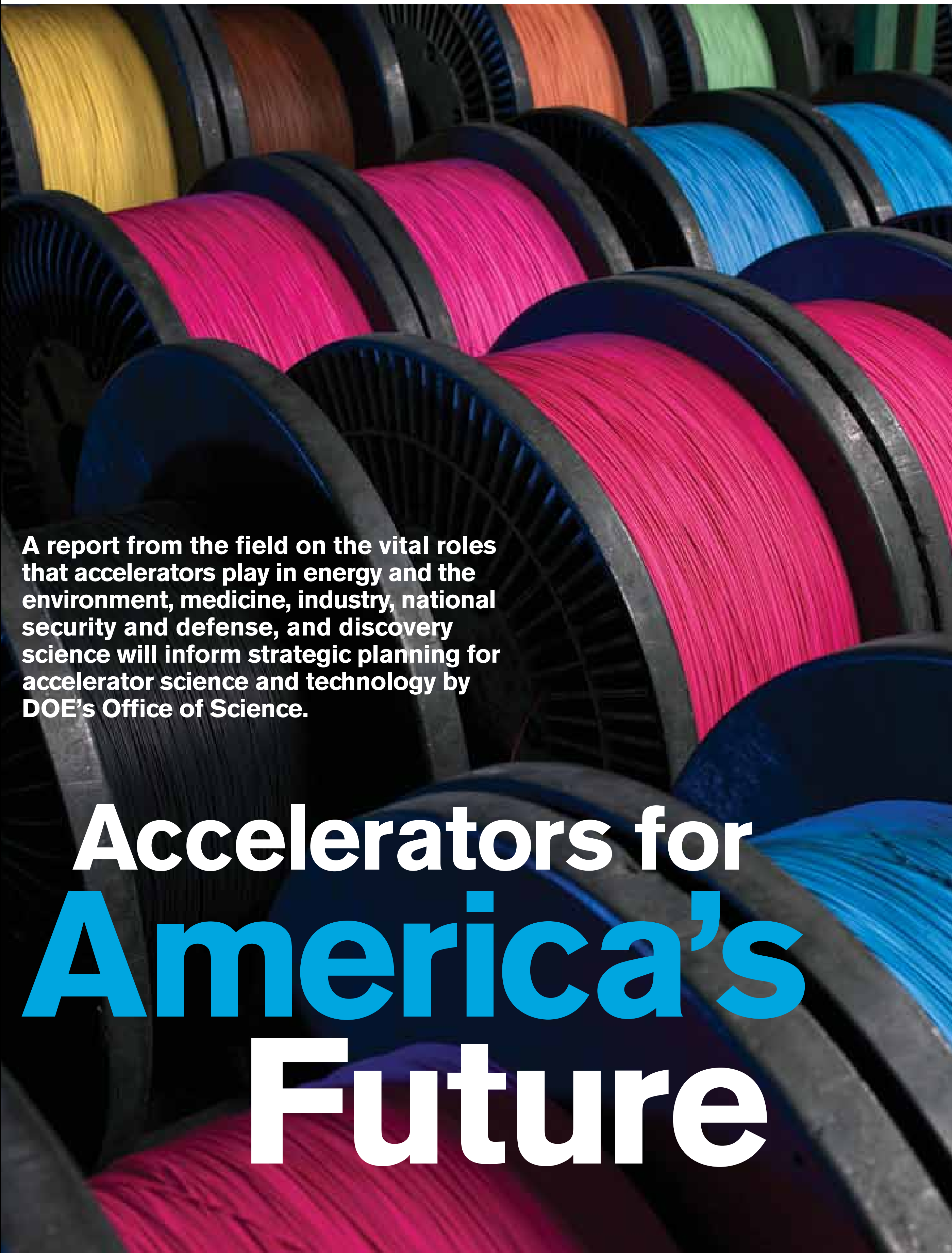
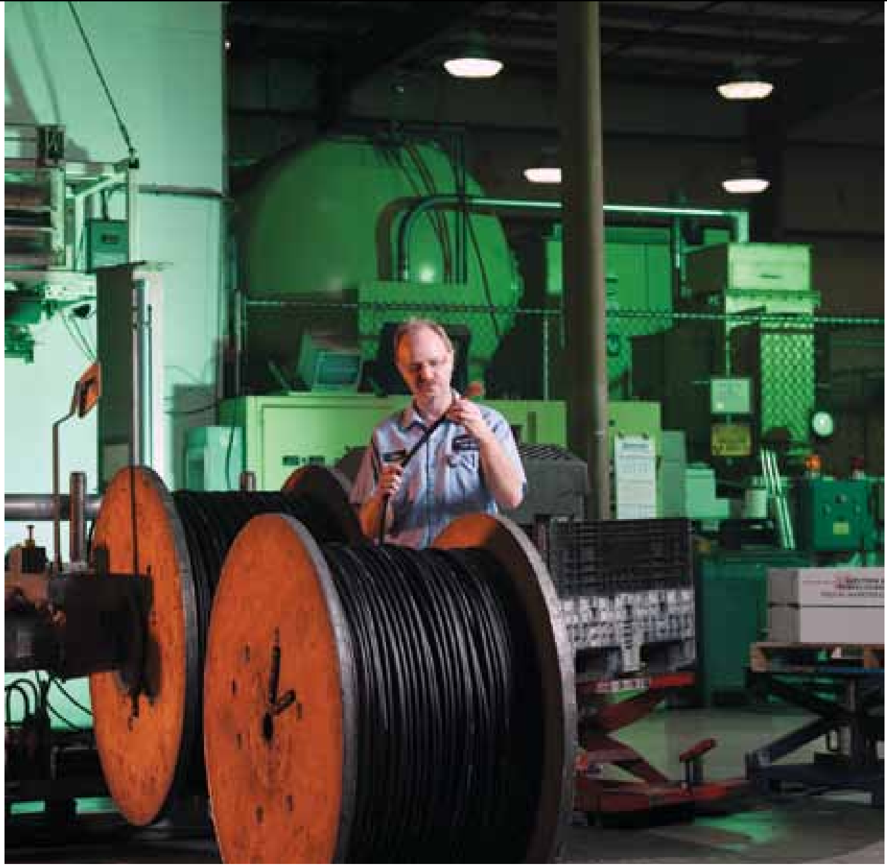


A report from the field on the vital roles that accelerators play in energy and the environment, medicine, industry, national security and defense, and discovery science will inform strategic planning for accelerator science and technology by DOE's Office of Science.

Accelerators for America's Future

Converting metal-coating facilities to electron-beam technology could realize a 95 percent savings in power demand. Coated cables at Electron Beam Technologies, Inc. in Kankakee, Illinois.

Photos: Reidar Hahn, Fermilab



A beam of particles is a very useful tool.

A beam of the right particles with the right energy at the right intensity can shrink a tumor, produce cleaner energy, spot suspicious cargo, make a better radial tire, clean up dirty drinking water, map a protein, study a nuclear explosion, design a new drug, make a heat-resistant automotive cable, diagnose a disease, reduce nuclear waste, detect an art forgery, implant ions in a semiconductor, prospect for oil, date an archaeological find, package a Thanksgiving turkey, or discover the secrets of the universe.

Particle beams to meet national challenges

The beams produced by today's particle accelerators address many of the challenges confronting our nation in the 21st century: energy, the environment, good jobs and economic security, health care, national defense, and the war on terror. The next-generation accelerators of tomorrow have the potential to make still greater contributions to the nation's health, wealth, and national security.

Incorporating innovative accelerator technologies into tomorrow's nuclear energy supply, for example, has the potential to make nuclear power safer and cleaner with far less nuclear waste. Electron beams could treat flue gases to make coal-fired plants cleaner and more environmentally friendly. They could detoxify waste water and make municipal water safe to drink.

Advances in beam therapy offer the promise of improving cancer treatment by maximizing the beam energy delivered to a tumor while minimizing the damage to normal tissue. Accelerators could serve as reliable alternative sources of critically needed medical isotopes currently made in nuclear reactors—some no longer produced at all in the United States.

In industry, accelerators represent cheaper, greener alternatives to hundreds of traditional manufacturing processes. For security and defense, compact, rugged, "fieldable" accelerators would have innovative applications from safe and reliable cargo inspection to monitoring international test ban compliance. The continuing development of accelerator technology will give scientists the tools for discovery across a spectrum of science from particle physics to human biology.

For the United States to remain competitive in accelerator science and technology, however, will require a sustained and focused program and changes in national policy.

Practical particles

The marquee superstars of the particle accelerator world are the giant research accelerators like Fermilab's Tevatron, Brookhaven's Relativistic Heavy Ion Collider, and most recently CERN's Large Hadron Collider in Geneva, Switzerland.

Behind the headlines, though, are the tens of thousands of accelerators that are at work every day producing particle beams in hospitals and clinics, in manufacturing plants and industrial laboratories, in ports and printing plants and, literally, on the ships at sea. Adding them all up, some 30,000 particle accelerators operate in the world today in medicine, industry, security and defense, and basic science.

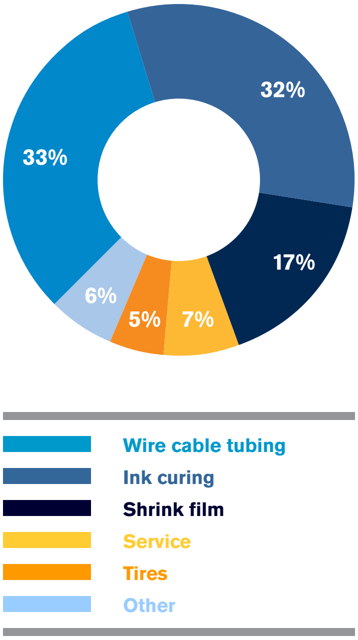
The market for medical and industrial accelerators currently exceeds $3.5 billion a year, and it is growing at more than 10 percent annually. All digital electronics now depend on particle beams for ion implantation, creating a $1.5 billion annual market for ion-beam accelerators. All the products that are processed, treated, or inspected by particle beams have a collective annual value of more than $500 billion.

Other nations have not been slow to recognize the potential for future applications of accelerators. European and Asian nations are already applying next-generation accelerator technology to current-generation challenges.

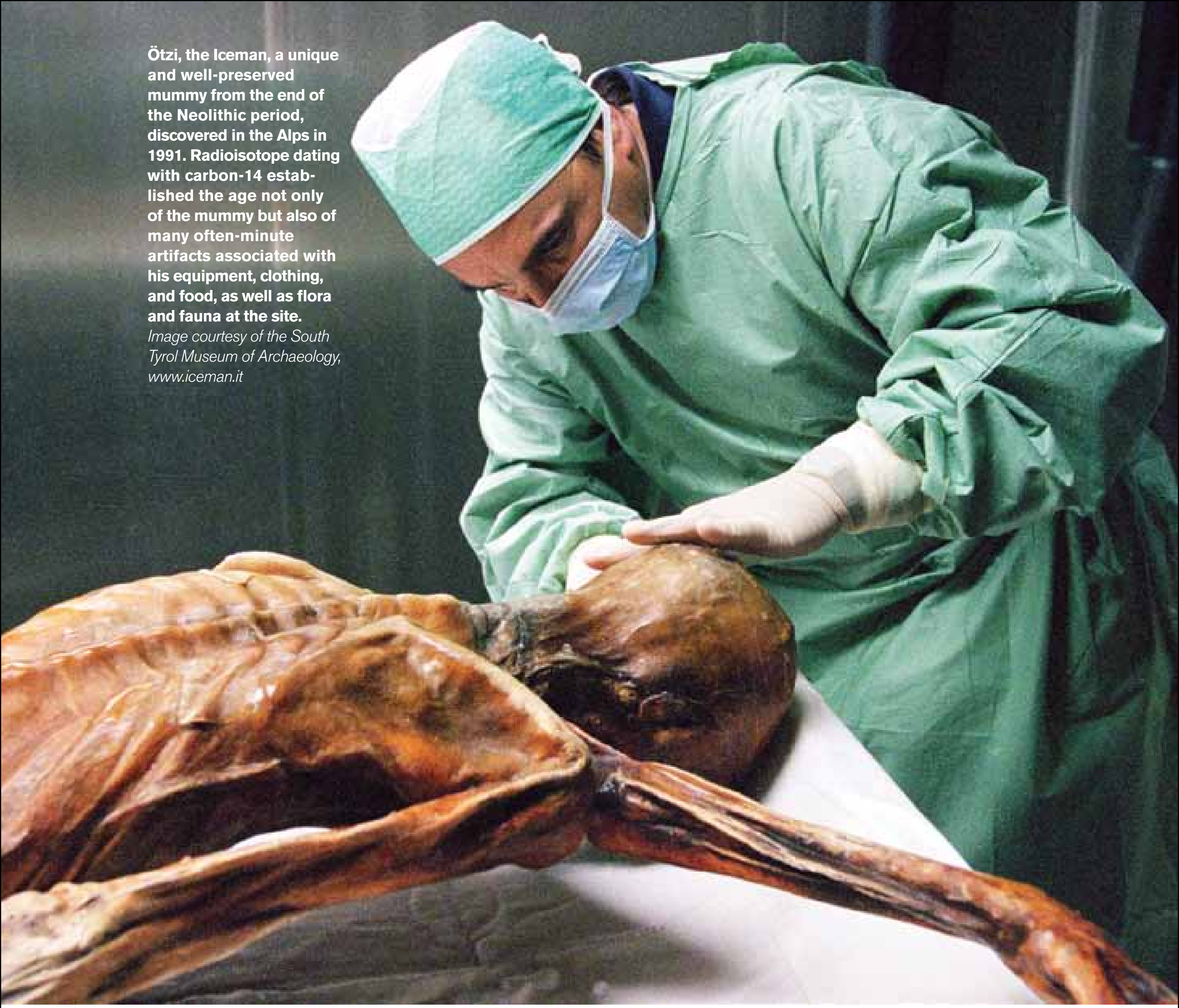
In March 2010, the Belgian government approved $1.3 billion for the MYRRHA project. It will demonstrate an accelerator-driven system for producing nuclear power and transmuting nuclear waste to a form that decays much faster to a stable non-radioactive form. The Belgian government estimates that the project will create 2000 long-term jobs. In China and Poland, accelerators are turning flue gases into fertilizer; and Korea operates an industrial-scale water treatment plant using electron beams. Cancer patients in Japan and Germany can now receive treatment with light-ion beams, and clinical centers with multiple ion beams are coming on line across Europe. US patients don't have these options.

The United States, which has traditionally led the world in the development and application of accelerator technology, now lags behind other nations in many cases, and the gap is growing. To achieve the potential of particle accelerators to address national challenges will require a sustained focus on developing transformative technological opportunities, accompanied by changes in national programs and policy.

Markets for industrial electron beams total $50 billion per year.
Image source: IAEA Working Material on Industrial Electron Beam Processing

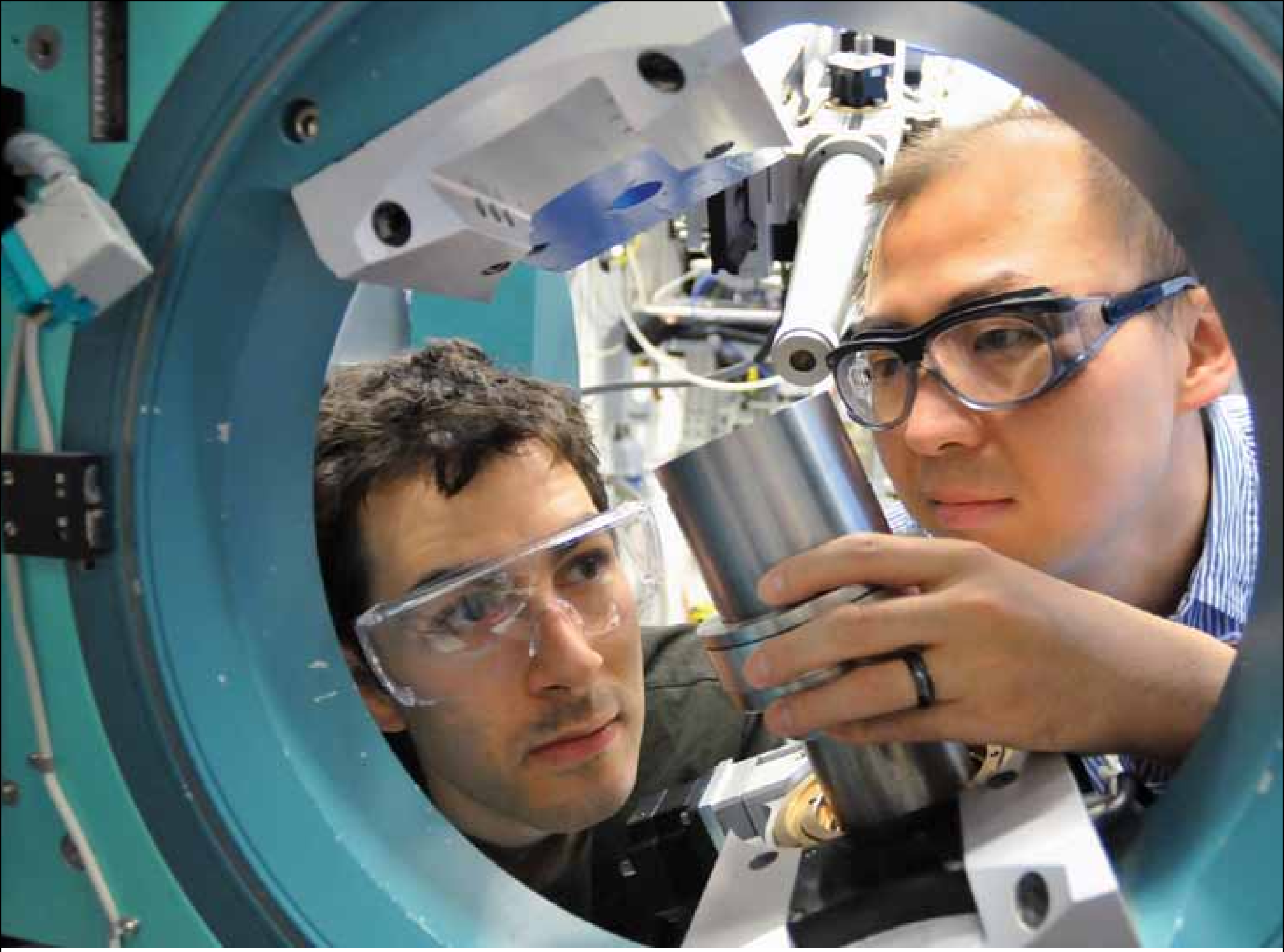


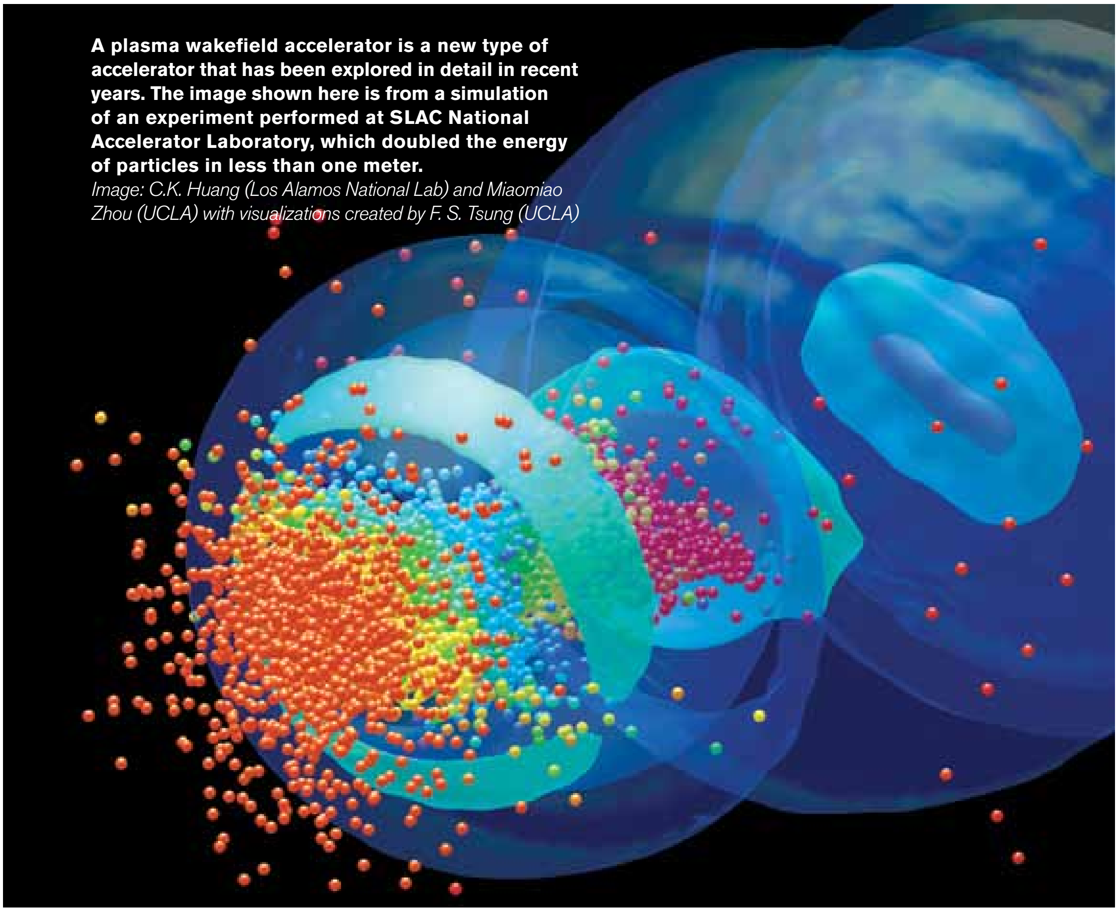
Research has demonstrated the effectiveness of particle accelerators for purifying drinking water, treating waste water, disinfecting sewage sludge, and removing pollutants from flue gases. (Right) Pilot flue-gas treatment plant in Poland.
Photo courtesy of A. Chmielewski, Institute of Nuclear Chemistry and Technology



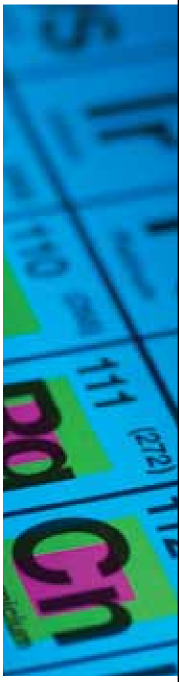
Ötzi, the Iceman, a unique and well-preserved mummy from the end of the Neolithic period, discovered in the Alps in 1991. Radioisotope dating with carbon-14 established the age not only of the mummy but also of many often-minute artifacts associated with his equipment, clothing, and food, as well as flora and fauna at the site.
Image courtesy of the South Tyrol Museum of Archaeology, www.iceman.it

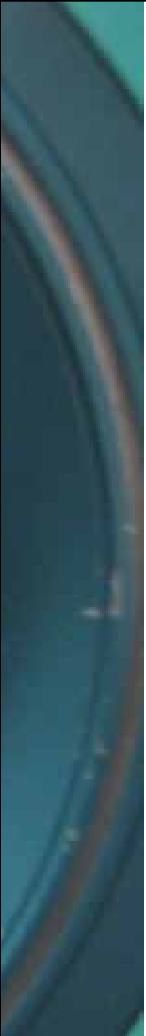
Most of the cereal boxes in the grocery store aisle are printed using electron-beam-cured inks and coatings. Their fast drying times allow for faster web-press printing.
Photo: Reidar Hahn, Fermilab





A plasma wakefield accelerator is a new type of accelerator that has been explored in detail in recent years. The image shown here is from a simulation of an experiment performed at SLAC National Accelerator Laboratory, which doubled the energy of particles in less than one meter.
Image: C.K. Huang (Los Alamos National Lab) and Miaomiao Zhou (UCLA) with visualizations created by F. S. Tsung (UCLA)





University of Chicago scientist Rafael Jaramillo and Argonne scientist Yejun Feng examine the element chromium at the Advanced Photon Source. Studying simple metallic chromium, the joint UC-Argonne team has discovered a pressure-driven quantum critical regime and has achieved the first direct measurement of a "naked" quantum singularity in an elemental magnet.
Photo courtesy of Argonne National Laboratory

From science to society

Historically, breakthroughs in accelerator technology have most often come from the realm of basic science research. The human imperative to discover the laws of nature, from the most fundamental interactions of matter to the behavior of the most complex biological systems, drives the search for ever-more-powerful investigative tools. Writing in 1916, J.J. Thomson, discoverer of the electron, described a famous example of the application of basic science research to immediate practical needs.

"By research in pure science," Thomson wrote, "I mean research made without any idea of application to industrial matters but solely with the view of extending our knowledge of the Laws of Nature. I will give just one example of the 'utility' of this kind of research, one that has been brought into great prominence by the War—I mean the use of X-rays in surgery…

"Now how was this method discovered? It was not the result of a research in applied science to find an improved method of locating bullet wounds. This might have led to improved probes, but we cannot imagine it leading to the discovery of the X-rays. No, this method is due to an investigation in pure science, made with the object of discovering what is the nature of Electricity."

Since the days of cathode ray tubes in the 1890s, particle accelerators have made an extraordinary evolution as tools of basic science. Between Ernest Lawrence's first four-inch-diameter cyclotron, built at Berkeley in the 1930s, and today's most powerful particle accelerator, the 16-mile-circumference Large Hadron Collider, have come dozens of progressively more powerful and precise machines, each incorporating innovations and breakthroughs to advance scientific progress. Each generation of particle accelerators builds on the accomplishments of the previous ones, raising the level of technology ever higher, a thrust that continues today. The National Academy of Engineering lists "to engineer the tools for scientific discovery" among its "Grand Challenges for the 21st Century."

Bridging the valley of death

Just as the investigation of electricity led to the discovery of X-rays, which found immediate use, the future of particle accelerators belongs not just to scientists. The powerful new accelerator technologies created for basic science and developed by industry will produce particle accelerators with the potential to address key economic and societal issues confronting our nation.

A critical challenge is the translation of breakthroughs in accelerator science and technology into applications that benefit the nation's health, wealth, and security. Experts from every field of accelerator science and technology, in the research community and industry alike, agree that making that happen will require bridging the divide often described as the "valley of death" that exists in the United States today between the research laboratory and the marketplace.

On one side of the valley are the innovative accelerator concepts and technologies that emerge, often in government-funded laboratories and universities, for basic research. On the other are industries that could put these new technologies to work to meet national needs—and compete in the global marketplace.

Keeping them apart are a dearth of funding mechanisms for research and development; a lack of national facilities, demonstration projects, and pilot programs to assist with the translation; an aversion to risk; and policies that inhibit coordination and partnership among government entities and between government and industry.

To address the challenge of innovation for national competitiveness in the domain of particle accelerators, the Department of Energy's Office of Science, the nation's major steward of accelerator technology, has inaugurated a program to coordinate basic and applied accelerator R&D. To better understand the direct connection between fundamental accelerator technology and applications, the Office of High Energy Physics sponsored an October 2009 workshop on behalf of the Office of Science to identify the R&D needs of the various users of accelerators who would benefit from future technology R&D initiatives.

Nuclear physics investigates how the fundamental building blocks of the big-bang plasma formed nucleons and nuclei, how astrophysical processes create the chemical elements, and how their interactions power the sun and the stars.
Photo: Reidar Hahn, Fermilab

Accelerator users and experts at the workshop focused on the potential role of accelerators in five key areas: energy and the environment, medicine, industry, national security and defense, and discovery science. They identified the opportunities and research challenges for next-generation accelerators; the most promising avenues for new or enhanced R&D efforts; and a path forward to stronger coordination between basic and applied research.

The accelerator stakeholders articulated the technical challenges and risks involved in achieving their vision for future accelerators and focused on changes in policy that would help to make the vision a reality.

Across the board, all groups strongly advocated the creation of large-scale demonstration and development facilities to help bridge the gap between development and deployment of accelerator technologies. They called for greatly improved interagency, interprogram, and industry-agency coordination.

Because continued innovation in accelerator technology depends on the next generation of accelerator scientists, they emphasized the need to strengthen the training and education of US accelerator scientists and engineers, and to recognize accelerator science as a scientific discipline.

The Office of Science will use the workshop's results, presented in this report, to develop a strategic plan for accelerator technology R&D that recognizes its broad national impacts.

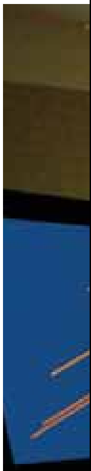
The 2005 National Academies report, *Rising Above the Gathering Storm*, issued a national call to action to address the eroding technological building blocks of future prosperity in the United States.

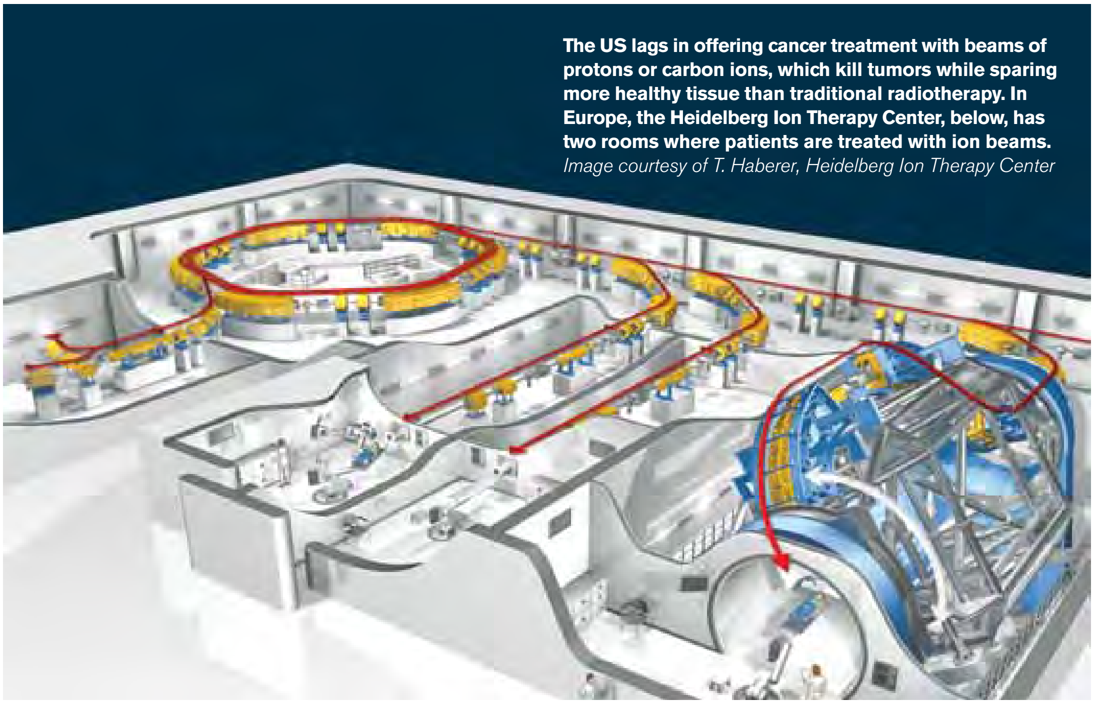
"This nation must prepare with great urgency to preserve its strategic and economic security," said the report's major finding. "Because other nations have, and probably will continue to have, the competitive advantage of low-wage structure, *the United States must compete by optimizing its knowledge-based resources, particularly in science and technology, and by sustaining the most fertile environment for new and revitalized industries and the well-paying jobs they bring*. (Italics added.) We have already seen that capital, factories, and laboratories readily move wherever they are thought to have the greatest promise of return."

For optimizing knowledge-based resources in science and technology, and for sustaining an environment for new and revitalized industries and the well-paying jobs they bring, a beam of particles is a very useful tool.

This text was excerpted with permission from the Accelerators for America's Future *report, which can be downloaded or requested in print at www.acceleratorsamerica.org*

Only a handful of US universities offer formal training in accelerator science and technology. More than any other factor, the education of the next generation of accelerator scientists and engineers will determine the future of accelerator-based science and technology in the United States.
Photo courtesy of W.A. Barletta





The US lags in offering cancer treatment with beams of protons or carbon ions, which kill tumors while sparing more healthy tissue than traditional radiotherapy. In Europe, the Heidelberg Ion Therapy Center, below, has two rooms where patients are treated with ion beams.
Image courtesy of T. Haberer, Heidelberg Ion Therapy Center

"Accelerators for America's Future," an October 2009 symposium and workshop, brought together stakeholders from across the spectrum of accelerator science and technology. Norman R. Augustine (above), retired chairman and CEO, Lockheed Martin Corporation, delivered the keynote address.

Photos: Reidar Hahn, Fermilab