Seeing the Impact

The socio-economic benefits of peaceful nuclear technologies

by Werner Burkart & Michael D. Rosenthal

The widespread use of "atoms for peace" brings tens of billions of dollars of benefits annually to people across the globe. They contribute to better medical care, food production, electricity generation, and manufacturing, for example.

In many countries today, nuclear and radiation technologies are established, dynamic components of national economies. But dollars and cents tell only part of the story, and figures are not equally available for all countries that apply nuclear technologies. Better assessments are needed of when, where, and why the atom's peaceful benefits can be realized, and as importantly, how they can be sustained.

The information is important for decision-makers and the public alike. Even the most novel or sophisticated nuclear techniques do not stand alone, and nuclear technology decisions must be framed in a larger picture. Nuclear applications have to be judged against their potential contributions and compared to conventional competitors. They must be measured, too, in terms of cost, reliability, safety, simplicity, sustainability and other factors central to plans of governments, private companies, research institutes and consumers.

For all these constituencies, more reliable information is needed to assist in making choices. In the nuclear area, the information is often rightly or wrongly shaped by perceptions and misperceptions about risk. In addition, new challenges—such as privatization in electricity production and health care—need to be taken into account to evaluate fairly the economic competitiveness and future of nuclear applications.

Through informed assessments, we can reach a better understanding of the impact of peaceful nuclear applications, which will help countries make better decisions on future uses. This article takes stock of the peaceful atom's social and economic impact and compares different approaches to assessing benefits. Such assessments can provide important insights about how nuclear applications can best serve the most pressing needs of the world's development.

How Wide an Impact?

The IAEA has rich and varied programmes to enhance existing nuclear techniques, or find new ones, and to transfer those providing tangible benefits to developing countries. Since 1957, more than US$1.2 billion worth of IAEA technical assistance, training and other support has helped countries put the peaceful atom to constructive work. The results are seen in important contributions that atomic energy makes to improve everyday lives of billions of people around the globe. Nuclear techniques make our food safer and more abundant; help prevent, diagnose, and cure disease; optimize sustainable water use; and protect the environment. Nuclear techniques have made significant contributions and have the potential to contribute much more in key areas of concern to the international community as identified in the Agenda 21 Action Plan, the Millennium Declaration, and at the World Summit on Sustainable Development (WSSD) in Johannesburg 2002.

As the IAEA seeks to "accelerate and enlarge" the contributions of "atomic energy," as its Statute sets down, it is important to understand in what ways these contributions have been made, how big they are, and what effects they have had. They could be evaluated solely in terms of their economic impact, but consideration also must go to the overall impact, taking into account environmental and other considerations. Indeed, a healthy and sustainable environment was identified as a prerequisite for success in achieving agreed WSSD goals.

Nuclear activities deployed worldwide and supported by the IAEA need to be assessed in terms of how they contribute to human welfare—including the welfare of individuals, the net effect on private firms, and the effects on the public sector. The impact on future generations needs to be understood. They will affect a society's resources—its institutions, its public knowledge, human capital, manufactured capital and natural capital. In an increasingly globalized world, national or regional contributions may also benefit a global community—not just a single society. In comparing the peaceful atom with other options for socio-economic development, the sustainability of newly introduced processes needs special consideration.

What are Nuclear Techniques?

Nuclear techniques to measure, manage, and change the world around us are used everywhere, but they defy easy characterization.

What is the nuclear contribution? How is it to be assessed? And what is the total impact?

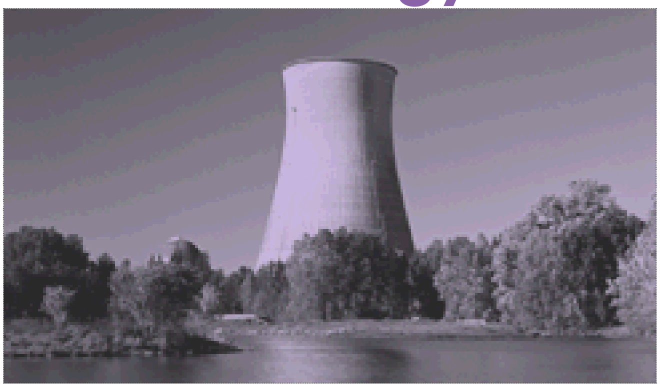
❶ In one group of activities, the nuclear contribution is relatively clear—for example, nuclear energy production, which is rooted in an established professional and industrial infrastructure. This encompasses nuclear fuel cycle activities performed by professionals with nuclear expertise that are regulated by nuclear authorities and dependent on a highly specialized industrial and knowledge pool. The impacts can be far-reaching, possibly affecting local wildlife, regional health conditions, or global climate trends in important ways.

❷ In a second group—such as diagnostic radiology, nuclear medicine, and radiation therapy—the required specialized infrastructure and knowledge pool also is evident. Doctors and technicians engaged in nuclear medicine perform billions of procedures per year worldwide that depend on a stable supply of isotopes or the safe use of radiopharmaceuticals and radiation technology. Their total "market value" is very large. But other impacts are difficult to quantify. How do parents, for example, evaluate the contribution of a nuclear diagnostic procedure that is a prerequisite to another surgical procedure that prolongs their child's life?

❸ A third group of nuclear applications—including plant breeding, food security, pest control, and water management—leads to results that become evident outside a specialized nuclear infrastructure or regulatory regime. They play an important role in national and regional enterprises providing the essentials of life—for example, adequate supplies of safe food and water. The impacts can be enormous and returns on investment large, even if they are difficult to measure. The successful introduction of a hardier plant variety may profoundly change large agricultural systems. The control/eradication of an insect pest can free farmers in the poorest countries from crippling constraints or empower them to overcome barriers to international trade. Changes in national economies can be significant.

The following snapshots in energy, agriculture, health, water, and industry exemplify specific aspects and develop some elements to quantify the peaceful atom's impact.

Nuclear Energy



Megawatt Dividends

Nuclear power generation is the most prominent but also the most contested nuclear activity. Worldwide, 441 nuclear power plants in 31 countries produced about 16% of the world's total electricity production in 2002. The nuclear share of electricity produced exceeds 75% in France, 30% in Japan, and 20% in the United States.

Clearly, the socio-economic impact of nuclear power production varies widely. At the economic level, the impact can be assessed by looking at the market value (retail prices) of the produced electricity. For Japan and the United States, this is estimated for 1997 at US $47 billion and US $39 billion respectively, according to Japanese researchers writing in the October 2002 edition of the *Journal of Nuclear Science and Technology.* This is about 0.5% of Gross Domestic Product (GDP) in both countries. In France, where the fraction of electricity produced by nuclear is considerably higher, this figure is about 1.5%. (These estimates are based on retail prices of electricity. Subtracting the transmission

NUCLEAR ELECTRICITY PRODUCTION

Drawing upon data in the IAEA's Nuclear Technology Review for 2002, the global contribution of nuclear electricity production can be estimated.

	Total electric TWh	Nuclear electricity TWh	Nuclear Share %	US$ (billions)
Global	15,000	2,500	16	125
US	3,800	770	20	39
Japan	940	320	34	16
France	520	400	77	20
France	520	400	77	20
Belgium	76	44	58	22
Lithuania	15	11	78	0.6

Notes: a kWh is valued at 5 cents (wholesale); figures from Nuclear Technology Review 2002 rounded.
Sources: IAEA; Journal of Nuclear Science & Technology (October 2002).

and distribution costs—non-nuclear components—would reduce the nuclear contribution by about twofold.)

Societal and environmental factors also have to be taken into account. Many are indirect and include value judgments and perception. Not all are included in electricity market prices. In looking at alternatives, some factors are easily quantifiable—for example, emissions of greenhouse gases or particulates—but difficult to assess for their impact on health and climate.

For nuclear, the costs of decommissioning nuclear plants, or the costs of long-term storage of nuclear waste are well understood, but the risk of accidents is open to large uncertainties. Funds for decommissioning and waste disposal are sometimes included in the costs of production. But for non-sustainable fossil fuel burning, operated on the "dilute and disperse" principle, the full cost remains unaccounted for. Therefore, comparative exercises have been complex in nature and prone to disagreements.

Food & Agriculture

"Green Revolution"

Major nuclear applications in food and agriculture are mutation breeding, pest control and food irradiation. Research relies heavily on nuclear techniques, such as for studies of soil erosion, water cycles, and environmental impacts.

For centuries, farmers and plant breeders have sought to improve plant varieties. Since the 1950s, there has been a concerted effort by international agricultural research centres and national agricultural research systems to improve agriculture in developing countries through the development of new crop varieties with higher yield or increased resistance to environmental stresses such as drought, salinity or pests. Thousands of new varieties have been released to become part of what has been hailed as the "Green Revolution".

Results have been impressive. Writing in *Science* magazine in May 2003, researchers R. E. Evenson and D. Gollin looked at the global impact of international agricultural research. They estimated that, today in developing countries, "in the absence of international research … caloric intake per capita in the developing world would have been 13.3-14.4% lower, and the proportion of children malnourished would have been from 6.1-7.9% higher." They further concluded that "virtually all consumers in the world have benefited from lower food prices."

Overall, Evenson and Gollin demonstrate that returns to consumers from the investments made in international agricultural research have been large. Yet at the same time, not all farmers benefit. Cheaper products from more efficient competitors often hurt small farmers, and higher yield plants have led to increased use of fertilizers to maximize their potential. Concerns have also arisen about the sustainability of intensive agriculture and the environmental consequences of soil degradation, chemical pollution, soil salinity, and biodiversity.

One major method used in the Green Revolution is known as "irradiation-induced mutation breeding" followed by selection of plants for desired traits. Although its role in achieving global results is difficult to estimate, it is clear that it is large. For example, the percentage of rice fields devoted to varieties produced with the help of irradiation in 1998 was at least 28% in Thailand, 19% in Laos, and 14% in Vietnam, researchers noted in the 2003 book, *Crop Variety Improvement and Its Effect on Productivity.* In Japan, researchers estimate that plant varieties produced via radiation-induced mutations command a market share of US $804 million annually, as reported in the October 2002 edition of the *Journal of Nuclear Science and Technology*. In Pakistan, 25% of the area for cotton is planted with a high-yielding mutant cultivar induced using gamma rays. It is estimated that this cultivar has contributed more than US $3 billion in cotton production and saved the textile industry of Pakistan when it was threatened by reduction in cotton production from insect pests.

Pest control using a method called the "sterile insect technique" (SIT) is also well established. It is used effectively for the Mediterranean fruit fly to protect citrus orchards and vineyards, and for the screwworm to protect cattle. Economic benefits per year for the United States from SIT are estimated at US $1.5 billion and US $1.3 billion, respectively, for these insects.

Protecting the environment from insecticides and preservation of biodiversity are additional benefits of this specific technology. The extension of SIT to the tsetse fly—which threatens both animal and human health and remains a major obstacle to African rural development—is progressing with considerable IAEA support and has already resulted in Zanzibar being free of this pest. As a result, farm-

SELECTED NUCLEAR APPLICATIONS IN FOOD AND AGRICULTURE

Application	Outcome	Value per year (US$)	Remarks
Mutation breeding			
⇛ Rice			
♦ Thailand	Export by Thailand	1989-98 $16.9 billion	
⇛ Cotton			
♦ Pakistan	Higher yielding crop		Contributed more than $3 billion to cotton production
Sterile Insect Techinique			
⇛ Mediterranean fruit fly	US citrus fruits & grapes	$1.5 billion	Estimate covers avoided costs
⇛ Mediterranean fruit fly	Chile exports	$33 million/year	
⇛ Screwworm	Eradication north of El Salvador	$1.27 billion	
⇛ Melon fly	Okinawa	$30 million/year	Not including avoided costs, reduced pesticides, etc.
Food irradiation			Very localised irradiation can reduce wide-spread use of antibiotics or release of fumigants
⇛ Spices	US Market (retail)	>$2 billion (estimate)	
⇛ Meat	US ground beef (retail)	≤$0.5 billion (estimate)	

Source: Reports to IAEA; Journal of Nuclear Science & Technology (2002); Crop Variety Improvement and its Effect on Productivity (2003).

ers there can now take better advantage of varieties of cattle with high yields of milk and meat. The number of farmers who do so has risen significantly since 1999, as has milk production and farm output.

The IAEA has initiated research and development at its Seibersdorf Laboratories to develop SIT for the control of malaria through area-wide suppression of mosquitoes. Considerable progress in rearing methods and gender selection still is needed. Field trials are being planned for the northern state of Sudan and French Reunion Island.

Another technology—food irradiation—has the potential to replace chemical fumigation for pest control in international trade, and is increasingly used to achieve safe foods such as ground meat or spices. Estimates for the United States, for example, show that less than 5% of ground beef is irradiated—but this is from a total market of 4 *billion* kilograms.

Food irradiation has been declared safe by the FAO/WHO Codex Alimentarius, the international food safety body. Yet public acceptance varies considerably, with many European countries restricting its use to spices. Public health and safety concerns are driving more interest. For example, irradiation, which offers a unique way to satisfy microbial hygiene requirements, could help satisfy stringent regulations for *Salmonella* germs in ground meat for school meals,

Industry

Key tools of the trade

In manufacturing and other industries, a key nuclear step may make only a small contribution to a discrete end product. In Japan, for example, almost all radial tires, with a market value of US $9 billion/year, are radiation treated to optimise cross-linking of rubber molecules. The global market is about US $35 billion.

A broad and diverse array of nuclear applications today finds routine industrial use. These include physical measurement gauges, humidity/density meters, oil well logging tools, and smoke detectors; radiation processing, for example sterilization of medical supplies, and plastic and rubber curing; and use of radioactive tracers to check performance and optimise processes in a wide range of industrial plants.

Worldwide, nuclear applications in industry account for an estimated market turnover of more than US $40 billion a year.

Although the initial nuclear inputs may have a relatively low dollar value, they often contribute in indispensable ways to much larger social and economic enterprises.

SELECTED INDUSTRIAL APPLICATIONS

Application	Output	Value (US$)
Electron Beam	♦ Radiation curing of tires	$35 billion global market, including $9 billion in Japan, $13 billion, USA
	♦ Sterilisation of medical products	$7 billion, Japan, USA
	♦ Coatings/Inks	$1.5 biillion
	♦ Flu gas cleaning	Plants in Poland, Japan, other countries
Radiation Processng	♦ 180 gamma irradiators	Plants for sterilization of medical products; foodstuffs
Non-destructive Testing	♦ Quality control, safety in manufacturing, auto, air, rail, oil, electronics industries	Reliance on NDT widespread
Stable Isotopes	♦ $30 million/year	

Sources: Repots to IAEA; OECD; Scientific literatures.

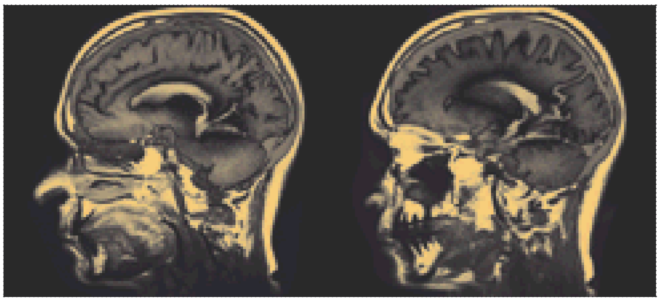
Water

Understanding lifelines

Today more than one billion people lack access to a steady supply of clean water. The Millennium Declaration resolved by 2015 to "halve the proportion of people who are unable to reach or afford safe drinking water" and to stop the unsustainable exploitation of ground water. Nuclear techniques in isotope hydrology play an important role in addressing this problem. Water samples have specific isotopic fingerprints that tell age, origin and climatic conditions. Nuclear techniques have become a basic tool to understand and manage water resources in a sustainable way. Water supplies, already scarce, will become more precious due to increasing demand from development and agriculture, by far the biggest consumer (consuming 70% of all water withdrawals from rivers, lakes, and aquifers). In Bangladesh, isotope studies led to a new understanding of the water resources available and have contributed as well to the understanding of how arsenic enters the water table. At a cost of about US $50,000, these studies have helped shape how a much larger investment, in excess of US $50 million, is being spent.

The impact can be enormous. Indeed tens of millions of people in Bangladesh and neighboring countries, poisoned by arsenic in the present ground water supply system, need to find a sustainable alternative. However, measuring the impact is difficult. In the absence of nuclear techniques, other methods would be used, although they cannot provide as good an understanding of complex water systems. Outcomes are yet to be fully realized.

Health



Multiple benefits

Nuclear applications in medicine serve multiple aspects of modern health care. They contribute significantly to prevention, diagnosis and cure.

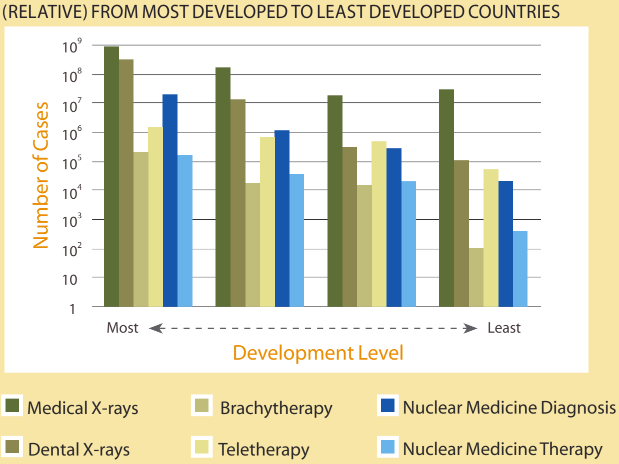
In the field of radiography, strides are big. From the visualization of the bones of Ms. Roentgen to modern radiology in dentistry and orthopaedics, X-rays have provided cheap and non-invasive means to understand pathological processes and to guide efficient treatment. Today, nuclear imaging applications range from relatively inexpensive dental X-ray machines to sites with their own accelerators to produce radioisotopes for positron emission tomography (PET) scans. Hardware investments can range from a few tens of thousands of dollars for an X-ray unit to millions of dollars for sophisticated nuclear imaging systems. X-rays are used almost everywhere for imaging, with more than 2 billion procedures annually. Seven out of 10 Americans received diagnostic X-rays in 2002. The use of some imaging techniques, such as PET, has grown quickly in recent years, with about 375 centres worldwide in 2002 and an investment in equipment of more than US $500 million.

Radiotherapy is widely used to treat cancer, with over 5000 treatment centers worldwide, treating millions of patients annually. Proton Therapy, on the other hand, is used in only 22 centres in 11 countries and has treated approximately 40,000 patients to date.

Radioactive tags in biomedical research are central to progress in genomics and proteomics. Physicians also turn to pharmaceuticals tagged with radioisotopes, which play a unique role in targeting specific organs, for both imaging and treatment. It is estimated that medical radioisotopes were administered to one third of the 31.7 million patients admitted to hospitals in the United States in 2000.

Although the US market for medical radioisotopes is in the range of US $100 million, its market for radiopharmaceuticals

RATES OF NUCLEAR MEDICINE PROCEDURES
(RELATIVE) FROM MOST DEVELOPED TO LEAST DEVELOPED COUNTRIES



Source: Adapted from UNSCEAR, Sources and Effects of Ionizing Radiation.

is in the billon dollar range and the annual cost of all procedures is estimated to be in the US $8-10 billion dollar range.

As the graph on the previous page shows, a strong gradient exists between advanced countries and least developed ones where the potential of nuclear in medicine is practically untapped. The Agency is working to help realize this potential, especially in treating cancer, whose dramatic rise across the developing world is straining already limited resources and equipment. The entire developing world has only about 2,200 radiotherapy machines while as many as 5,000 machines might be needed to help patients fight cancer. Experts predict a long-term crisis in managing cancer, with an estimated five million new patients requiring radiation therapy every year. Providing essential equipment and training of staff to safely treat cancer patients in the developing world is of increasing importance to the IAEA. At least 50% of cancer victims can benefit from radiotherapy that destroys cancerous tumors.

FRAMEWORKS FOR ASSESSMENT

In viewing these snapshots, it is necessary to keep in mind the importance of the frameworks within which they take place. On the international level, the Nuclear Non-Proliferation Treaty, the Convention on the Physical Protection of Nuclear Material, the Nuclear Safety Convention and others set forth basic norms. Nonetheless, nuclear safety, security and radiation protection, and the governance of laws, rules, and regulations, remain basically national prerogatives.

Creating and maintaining the appropriate nuclear safety and security infrastructure—both international and national—is a prerequisite for a sustainable nuclear economy. However, many applications or socio-economic benefits derive from nuclear applications that do not involve ionizing radiation and hence are outside nuclear regulatory control. Stable isotopes in water resources and nutrition, as well as biomedical tests and improved crop varieties, are important examples.

In these areas, due regard must be given to the non-nuclear infrastructure needed to apply sophisticated techniques on a wide basis and to conform to the specialized requirements of an increasingly globalized world—as is the case in food distribution. As awareness grows of the potential negative impact of non-nuclear methods for the production and distribution of food and energy, increasing attention needs to be paid to areas where nuclear sciences and applications can provide cost effective and low-risk alternatives.

At this stage in the evolution of “atoms for peace”, some points are worth noting, as we try to better assess how peaceful nuclear science and technology contributes to our shared global environment and development.

✔ On the national and regional level, nuclear sciences and applications are still a core discipline for academia and industry on the road to a technologically advanced society.

✔ All countries take advantage of nuclear applications, especially in health care. While utilization increases dramatically with national social, technological, and economic development, significant socio-economic benefits can be obtained at all levels of development.

✔ To best realize these benefits, the contributions have to be properly embedded into major economic activities such as agriculture, health and energy. Accurate assessments of their costs, benefits, and risks are needed.

✔ An open competition based on comparative assessments has demonstrated that nuclear sciences and applications often provide the tool of choice, sometimes the only choice. Continuing assessment is needed to ensure that the benefits of nuclear applications are available in those areas where it is worth utilising the atom.

✔ Major benefits have accrued to both developed and developing countries. Investments in the requisite technical and political infrastructure can be rewarded relatively quickly, even though some aspects may need many years to mature.

✔ Especially in areas not driven by private industry, transfer of human, regulatory, technical and scientific nuclear capabilities in food and agriculture, health, and environment remains an important mandate of the IAEA.

✔ A numerical estimate/range of nuclear applications on the global scale is prone to many uncertainties. Electricity production, medicine, industry, food and agriculture all depend in important ways on the energy of the atom. All applications combined may amount to several percent of GDP in highly developed countries.

✔ The IAEA remains dedicated to the identification, evaluation, facilitation and transfer of nuclear sciences and applications to all Member States. The experiences of the richest economies demonstrate that there remains a large, untapped potential for nuclear sciences and applications to contribute significantly to meeting basic human needs around the world.

✔ Clearly, much more needs to be done to bring to bear *all* the tools of science and technology in the fight against poverty and the quest for sustainable development. Nuclear applications have shown they can contribute positively toward these goals. Understanding more about them, and sharing the experience and lessons learned, will be an important component of tomorrow’s progress.

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