# The Atom, the Environment and Sustainable Development

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# The Atom, the Environment and Sustainable Development

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# Foreword

The IAEA has a broad mandate to facilitate nuclear applications in a number of areas and scientific disciplines. A fundamental component of the Agency's mandate is to enhance the peaceful contribution of nuclear science and technology to the specific development needs of its Member States in areas such as industry, human health, agriculture and nutrition. Nuclear techniques play an important role in addressing these development challenges. By facilitating their use, the IAEA is contributing to sustainable development. Well known examples include helping to advance treatment methods for fighting diseases, improving access to electricity, and increasing food security.

A major underlying challenge in development for many Member States is environmental degradation. Environmental issues affect local, national, regional and global communities and threaten to undermine human well-being. Addressing these issues in a timely and efficient manner is essential. As with the other areas mentioned above, nuclear science and technology can make a particularly valuable contribution to assisting with efforts to better understand and protect the natural environment.

Through *The Atom, the Environment and Sustainable Development*, the IAEA aims to raise and widen awareness of the unique contributions nuclear science and technology can make to the *environmental* dimension of sustainable development. Through this publication and other reports, I expect our readers to acquire a better and more precise understanding of the significant role of science and technology, including nuclear-related technology, in the global development agenda. This publication also highlights the IAEA's role in supporting developing countries to realize their sustainable development aspirations through technology transfer and capacity-building.

Yukiya Amano
IAEA Director General

# The IAEA and the Environment

Protecting the natural environment is one of the three fundamental pillars of sustainable development.[1] Yet in the 21st century, development is increasingly threatened by widespread environmental pollution and planetary-scale changes that affect the climate, the biosphere, the water cycle, and the ocean. Unprecedented levels of fossil fuel consumption are driving climate change, extreme weather events, water scarcity and ocean acidification. At the same time, unsustainable extraction of natural resources combined with wide-scale destruction of natural habitats due to urban development and agricultural expansion are reducing biodiversity and impacting the balance and stability of ecosystem services[2] on which humans depend for their livelihood and economic progress.

Municipal and industrial effluents, as well as runoff from agricultural land, transfer large quantities of nutrients, heavy metals, pesticides, chemicals and petroleum hydrocarbons that can harm inland water resources and coastal and marine ecosystems. These coastal ecosystems and marine life also face the continuous risk of oil spills from ships and oil platforms.

The negative effects of development on the natural environment and the bioaccumulation of radionuclides, metals and organic contaminants in food products may pose a significant problem for economies that are highly dependent on environmentally based sectors such as fisheries, agriculture and tourism, or sectors requiring reliable and clean water supplies.

Effectively and efficiently responding to the challenge of environmental degradation urgently requires improving the understanding of environmental processes and implementing comprehensive monitoring programmes. This action will enable Member States to make informed decisions, implement targeted measures to protect the environment and assure the sustainable delivery of ecosystem services.

Nuclear, isotopic and related analytical techniques and technology are valuable tools for gaining an understanding of the environment and for addressing a broad range of environmental issues. The IAEA supports its Member States in enhancing their capacities to use these advanced scientific techniques and tools to tackle environmental threats. The IAEA also makes a number of contributions to furthering work on the environmental dimension of sustainable development in areas ranging from water issues to agriculture and animals to nutrition and human health. These various contributions will be highlighted in this publication.

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1 Governments attending the Rio+20 Summit, in articulating "The Future We Want", committed to work together to comprehensively address the three dimensions or pillars of sustainable development, namely sustained and inclusive economic growth, social development, and environmental protection.

2 An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the non-living environment, interacting as a functional unit. Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth.

# Understanding the Environment

One of the first and most important steps in protecting and managing the natural environment is to unravel its complexity and determine as precisely as possible how the environment functions as a system. Questions such as 'How do pollutants move through the environment?' and 'How are individual species or various ecosystems impacted by individual pollutants or multiple pressures?' must be addressed to ensure that management actions are effectively and efficiently operationalized.

The IAEA assists its Member States in the application of nuclear techniques and technology to develop an incisive understanding of these complexities and facilitate the protection and management of the natural environment.

## Water and Climate Change

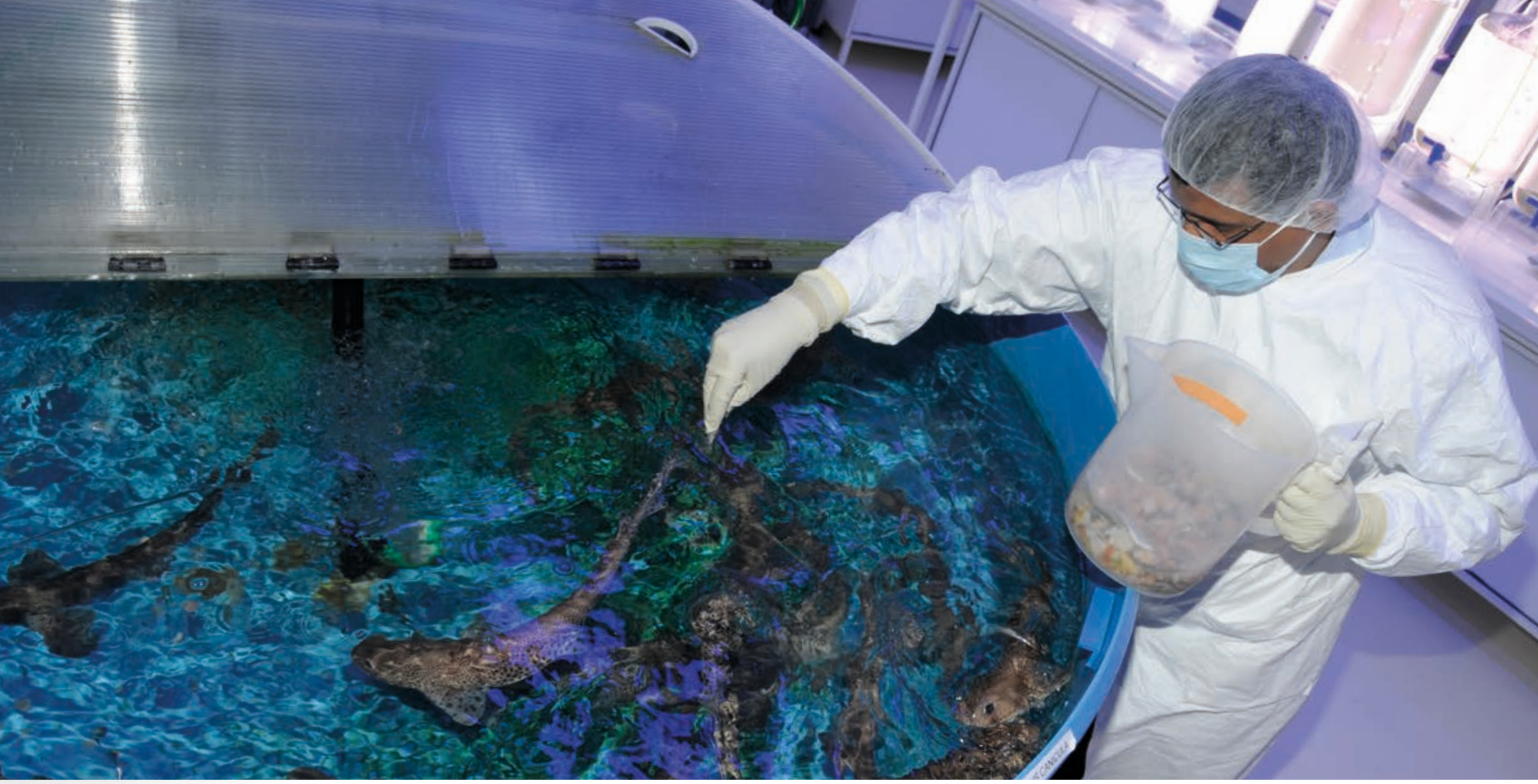
Water serves as the fundamental link between the climate system, human society and the environment. It is therefore critical to understand changes in the water cycle at different spatial and temporal scales. The increased frequency and intensity of droughts, floods, storm surges, and landslides related to climate change will put additional strain on water resources and increase uncertainty about the quantity and quality of water supplies.

The IAEA is enabling Member States to use isotopic techniques to precisely understand the impact of climate change on water resources and to manage those resources sustainably. For example, isotopes of oxygen and hydrogen in precipitation are used to understand climate impacts on the present water cycle and throughout the Earth's history. These isotope data sets are provided by the IAEA's global network of isotopes in precipitation (GNIP), which was established in 1961. For more information access: www.iaea.org/water

## Groundwater and Surface Water Interactions

Isotopic techniques also help to determine better and more sustainable management approaches for groundwater and surface water interactions. Groundwater is the largest freshwater source available and is currently used to meet domestic, industrial and agricultural demands. The current groundwater supply may have last been replenished thousands to millions of years ago, and using isotopic techniques to track and date it provides estimates on the rate of water replenishment, depletion and volume of aquifers.

Furthermore, groundwater recharge can come from rivers and wetlands, while river flows and wetlands can be reduced by depleted subterranean aquifers. Using isotopic techniques can be effective for monitoring and managing the river-groundwater interactions. The IAEA global network of isotopes in rivers (GNIR) provides scientific data to support further water research and management studies.



## Water Quality and Pollutants

In addition to better understanding quantities and fluctuations in water sources, nuclear and isotopic techniques can also reveal scientific information about water quality and pollutants. The IAEA facilitates the use of the isotopic techniques to identify sources of water pollutants, their transport pathways and their impacts on rivers, groundwater, marine environments and coastal ecosystems. For example, analytical methods have been developed and applied to measure the isotopic signatures of lead in marine samples. These methods help to identify sources of lead and investigate pollution processes. Similarly, isotopes of carbon and nitrogen are used as indicators of eutrophication in aquatic ecosystems, while lipid biomarkers and their isotopic composition are used to study the origin and dynamics of organic matter in the environment, as well as to fingerprint sources of petroleum contamination.

Nuclear science also provides tools to further examine and understand coastal circulation/ residence times, the transit times of contaminants in drainage basins, the transfer of contaminants from atmosphere to ocean and between sediment and water, and in dating the deposition of contaminants in coastal sediments. For more information access: www.iaea.org/water

## Ocean Acidification

The IAEA assists Member States in using nuclear and isotopic techniques to examine decreasing pH levels in the world's seas and oceans (ocean acidification) and to investigate the responses of marine organisms to changes in seawater chemistry.

Several important biological processes affected by ocean acidification - including calcification, biomineralization, metabolism, primary production, nitrogen fixation and bioaccumulation of trace elements - are being studied by the IAEA using nuclear and isotopic techniques. Information gathered from this study can help to estimate the impacts of ocean acidification on key commercial species and to evaluate risks to the environment and to society. Changes resulting from ocean acidification can have significant implications on industries involving shellfish production and, ultimately, threaten seafood security.

Scientists also use nuclear and isotopic techniques to study 'environmental archives', such as fossilized marine organisms buried in sediment on the ocean floor or the skeleton of long-lived corals, which reveal past trends in ocean acidification over millennia. These organisms form calcareous shells or skeletons that contain a relative amount of certain isotopes that change in quantity based on the pH levels of the seawater at the time of formation. Identifying the isotopic ratios in the shells can provide indirect measurements of pH levels in the ocean, which is not only useful for uncovering past ocean acidification events, but is also crucial for testing and building models to project future acidification scenarios.

The Ocean Acidification International Coordination Centre (OA-ICC) at the IAEA laboratories in Monaco was launched in 2012 to serve those concerned with ocean acidification, such as the scientific community, policymakers, media and the general public. Activities of the OA-ICC include supporting the development of an international observing network; collaboration between natural, social and economic sciences; encouraging the use of best practices; maintenance of online ocean acidification databases; capacity building; and knowledge exchange. For more information access: http://www.iaea.org/ocean-acidification

## Oceanic Carbon Cycle

Understanding the mechanisms that influence the flux of material from the ocean surface to the seafloor or depth remains an outstanding issue in marine biogeochemistry. Improving our understanding of these processes is, among other things, fundamental to enhancing the accuracy of climate change models. 'Sinking particles' are ultimately responsible for the removal of many biologically and particle reactive elements from the ocean. These particles include atmospheric carbon, which is converted from carbon dioxide ($CO_2$) to particulate phases during biological production and are sequestered to deep water via particle sinking. By analyzing suspended particulate matter from various ocean depths, the IAEA is able to assess various factors controlling the transfer of carbon from the surface to the deep ocean.

As particles fall to the ocean floor, the organic carbon remineralizes into inorganic forms, which is much more easily released and redistributed into ocean waters at various depths. The extent of this redistribution determines how much

$CO_2$ the ocean can absorb from the atmosphere. The natural radionuclide thorium-234 ($^{234}$Th) has increasingly been used to quantify particle fluxes and carbon export from the upper ocean in both open-ocean and coastal environments. $^{234}$Th is a particle-reactive isotope that is produced in seawater by radioactive decay of its dissolved conservative parent uranium-238 ($^{238}$U). The disequilibrium between $^{238}$U and the measured total $^{234}$Th activity reflects the net rate of particle export from the surface ocean on time scales of days to weeks.

## Marine Organisms: Bioaccumulation of Contaminants

The IAEA conducts research on the accumulation of contaminants in marine organisms using radio-isotopic tools in order to have a precise understanding of how contaminants are affecting organisms and subsequently the trophic food chain. Different exposure pathways are studied including seawater, food and sediments.

The nutritional needs of selected marine biota are also investigated by the IAEA. For example, the trophic transfer of essential elements such as cobalt (Co), manganese (Mn) and zinc (Zn) (using radio-isotopic equivalents) is studied to improve knowledge in the field of aquaculture.

## Soil-Water-Plant Systems

An increased demand for food (>60%) and agricultural production is anticipated over the next half century. As supplies of water and fertilizer are stretched in many regions across the world, and as soil fertility and quality deteriorate, global food security is becoming a significant challenge.

The IAEA in partnership with the Food and Agriculture Organization of the United Nations (FAO) uses nuclear and isotopic techniques to clearly understand the complex interactions occurring in soil-water-plant systems. These techniques can assess the relative value of select soil-water-crop management technologies and practices that are tailored to specific agro-ecosystems. For example, soil moisture neutron probes are used for monitoring changes in soil water content, which is useful information for scheduling irrigation. Gamma density probes are used to measure changes in soil bulk density. The Nitrogen-15 ($^{15}$N) technique can be used to quantify biological nitrogen fixation (BNF) by legume crops, crop nitrogen use efficiency, and to identify sources of pollution in ground and surface waters. The heavy isotope of carbon-13 ($^{13}$C) is preferentially discriminated compared to the lighter isotope carbon-12 ($^{12}$C) during photosynthesis depending on water availability and soil salinity. As a result, the relative abundance of the two carbon isotopes ($^{13}$C/$^{12}$C ratios) in plant tissues is different and can be used as a surrogate marker for crop water stress, crop water use efficiency and crop tolerance to drought and salinity. The use of the oxygen-18 ($^{18}$O) isotopic signature in water vapour can help to determine how much water is lost through

soil evaporation and transpiration from plants under different management practices. For more information access: http://www-naweb.iaea.org/nafa/index.html

## Soil Erosion

Good catchment / watershed-scale management requires the ability to identify sources of mobilized sediment for the purposes of remediation, rehabilitation and source control measures. The compound-specific stable isotopic (CSSI) technique offers one of the best tools to identify sources of soil erosion and sedimentation. CSSI techniques are based on the measurement of $^{13}C$ natural abundance signatures of specific organic compounds in soil or sediment. The IAEA uses both naturally occurring and man-made isotopes (fall-out radionuclides) to determine soil erosion, as well as deposition rates and patterns, and to evaluate the efficiency of soil conservation and management measures. These radionuclides can be used to assess the impacts of climate change on land degradation and soil erosion so that appropriate management practices can be effectively targeted to preserve both soil and water resources.

## Agriculture and Climate Change

Agriculture continues to contribute approximately 6.6 billion tonnes of $CO_2$-equivalent per year of global greenhouse gas (GHG) emissions to the atmosphere in the form of carbon dioxide, nitrous oxide and methane. Agriculture must undergo a significant transformation to reduce GHG emissions, address land degradation and improve land and water quality.

The IAEA, in partnership with the FAO, provides Member States with technologies and practices using isotopic and nuclear techniques to better understand and manage land and water resources in agricultural catchments and to reduce GHG emissions from agricultural activities. The stable isotopes of $^{13}C$ and $^{15}N$ are useful for identifying sources of GHG emissions from soils and help to develop land management

practices aimed at reducing emissions. The use of $^{13}C$ also helping to identify stable pools of carbon in soil and supports the development of land and crop management strategies to maximize soil carbon sequestration in agriculture. For more information access: http://www.fao.org/climatechange/climatesmart/en/

## Nitrogen Sources in Agriculture

The increase in agricultural productivity achieved over the past five decades was accompanied by a significant increase in the use of inorganic nitrogen (N) and phosphorous (P) fertilizers. Between 1961 and 2008, global fertilizer consumption increased from 30 to over 160 million tonnes, with an annual average increase of 2.5 million tonnes. However, the efficiency of fertilizer N and P ranges from 10 to 30 percent in the year that it is applied. While it is clear that N and P losses from croplands occur, understanding how land management practices affect these losses and their potential impact on water resources is important for good environmental management. The IAEA, in partnership with the FAO, assists Member States to use both naturally abundant and enriched $^{15}N$ isotopes to identify losses of nitrogen from agricultural landscapes and the sources of N in water resources.

## Animal Digestion

The IAEA, in partnership with the FAO, supports isotope-aided research in an effort to foster and facilitate a further understanding of the internal digestive process in hoofed farm animals and the effects of diet. These studies provide a base for improving digestibility in livestock, which in turn increases feed conversion rates and energy utilization with reduced GHG emission per unit of product.

Improving food digestibility in hoofed farm animals can increase production and decrease GHG emissions. Diet balancing can improve digestibility and lead to an improved fermentation process by the microorganisms inside the animals' digestive systems. These

microorganisms produce volatile fatty acids that provide nutrients to the host animals. This process also leads to the growth of microbial masses, which satisfies a portion of the protein needs of the host animals.

Isotopic techniques enable scientists to measure the rate that microbial protein masses are synthesized by tracking certain purine derivatives detectable in the animal's urine. Similarly, certain minerals and elements can be labelled and tracked to investigate mineral imbalances, determine passage rates and to estimate carbon dioxide production.

## Livestock Genomes

Identifying targeted genes and characterizing indigenous and adapted livestock genomes can facilitate the identification of advantageous gene traits, such as the ability to thrive under climate or nutritional stress, or the resistance to diseases like gastrointestinal parasites and trypanosomosis. The IAEA uses a range of nuclear and isotopic methods for genetic characterization to support marker-assisted breeding of livestock for better productivity and adaptability. These rely on techniques such as isotope-labelled DNA probes and dot-blot hybridization techniques that utilize $^{32}P$, and radiation hybrid mapping that employs $^{60}Co$ and other isotopic markers. These methods are often used in combination with nuclear-related biotechnologies, such as polymerase chain reaction (PCR), microsatellite analysis, single nucleotide polymorphism, and next generation sequencing.

## Behaviour of Radionuclides in the Environment

Understanding the complex behaviour of naturally occurring radioactive isotopes in the environment can help scientists better understand environmental processes and improve public safety. The IAEA is preparing a series of documents covering the behaviour of elements such as radium, polonium, thorium and uranium. For more information access:
http://www-pub.iaea.org/books/IAEABooks/10478/The-Environmental-Behaviour-of-Radium-Revised-Edition
http://www-pub.iaea.org/books/IAEABooks/10369/Measurement-and-Calculation-of-Radon-Releases-from-NORM-Residues

# Protecting People and the Environment

Protecting the environment is far more cost effective than cleaning or repairing the environment. With a forecasted population increase from seven billion in 2014 to nine to ten billion in 2050, it is of paramount importance that nations across the globe move to a greener model of development. Undoubtedly this model will need to embrace the many benefits to be derived from nuclear science and technology.

## Setting the Standard

Since 1957, the IAEA has been one of the main international organizations leading the efforts to develop principles, policies and standards to protect the public and the environment from the harmful effects of ionizing radiation.

Publications in the IAEA Safety Standards Series reflect international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. The procedure for developing the IAEA safety standards is a well-defined and transparent process. It includes gathering and integrating the knowledge and experience gained in Member States. The Safety Standards Series are continuously reviewed and improved based on contemporary scientific knowledge and broad practical experience gained from the application of the standards. Regular improvements integrate emerging trends and issues.

Publications in the IAEA Nuclear Energy Series provide guidance and information related to nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning of facilities, including general topics relevant to all of these areas. The information in this series builds on the expertise of Member States' representatives participating in technical working groups.

Publications in the IAEA Nuclear Energy Series also assist Member States with research and development as well as practical applications of nuclear energy for peaceful purposes. This includes practical examples and lessons learned that can be used by utilities, owners and operators of facilities, technical support organizations, researchers and government officials, among others.

These two IAEA series are elements of an international framework of legal instruments, international standards and guidance, national requirements and industry standards which, as a whole, provide a comprehensive system for effectively managing nuclear energy and managing radioactive waste so as to protect people and the environment from harmful effects of ionizing radiation.

## Clean Technology

Nuclear and isotopic technologies have a successful history of being used to create innovative products and processes that are increasingly environmentally friendly. For example, radiation sterilization of medical devices alleviates the use of toxic ethylene oxide gas. Similarly, surface curing using radiation processing is energy efficient and enables users to comply with restrictions on the emissions of volatile organic compounds (VOCs) which can form greenhouse gases.

The development of the process of radiation crosslinking of polymers has led to the growth of an entirely new industry to produce polymeric products which are free from chemical additives and possess unparalleled physical and chemical characteristics. Another novel application of radiation technologies has been in the area of developing products based on natural polymers to produce value-added environment-friendly products. Radiation technologies have also been successfully deployed to treat industrial pollutants such as $NO_x$ and $SO_x$ (nitrogen and sulphur oxides present in flue gases) and effluents from the textile dye industry, as well as to sanitize sewage sludge for agricultural applications and to treat toxic PCBs (polychlorinated biphenyls) present in transformer oil.

The IAEA has been at the forefront of recognizing the need to develop appropriate technologies to meet the challenging task of addressing evolving environmental issues. Recent IAEA studies have focused on radiation-initiated degradation of organics to transform various pollutants into less harmful substances or reduce them to the levels below permissible concentrations. For more information access:
http://www-naweb.iaea.org/napc/iachem/working_materials/RC-1188-2-report.pdf
http://www.sciencedirect.com/science/article/pii/S0969806X11004324

## Biogas Technology

The IAEA contributes to global efforts to improve the use of biogas. Biogas is generated by the decay of organic matter, such as manure. During storage and processing, microbial activity transforms organic matter into methane and nitrogen, which leads to nitrous oxide emissions. These emissions increase when the organic matter is managed in bodies of liquid, such as deep lagoons or holding tanks. Labelling stable nitrogen-15 in this organic matter can help to monitor the nitrogen excreted into the environment in order to generate data regarding GHG emissions. According to the FAO, converting all cattle manure into biogas instead of letting it decompose could reduce global GHG emissions by 4 percent or 99 million tonnes.

## Sustainable Base-Load Power Generation

The IAEA is closely involved in energy-economy-environment (3E) analyses and techno-economic assessments related to sustainable development and, in particular, sustainable energy development. The IAEA conducts extensive research in these areas and has found that GHG emissions from nuclear power plants are negligible and nuclear power, together with hydropower and wind based electricity, is among the lowest $CO_2$ emitters when considering emissions over the entire life cycle.

Additionally, the IAEA engages in the analyses of the vulnerability, impact and adaptation options across a range of power generation technologies: coal, oil, gas, nuclear, hydro, wind and solar. Results show that climate change will particularly affect nuclear and other thermal power plants with long economic lifespans of 50+ years. To reduce the vulnerability of existing energy facilities and infrastructure to extreme weather events, investments are required globally. New long-lasting energy investments should be designed as 'climate-proof' with a view to withstanding the projected future climate and weather characteristics, including rising sea levels and extreme storm events. For more information access: http://www.iaea.org/OurWork/ST/NE/Pess/climate.html

## Managing Discharges from Radiological Sources

Both natural and artificial radioactive materials are widely used in medicine, industry, agriculture and research, and in the energy sector. These activities generate a variety of radioactive residues (solid, liquid and gaseous) that need to be managed in a safe and secure manner. Discharges of small amounts of radioactive waste to the environment are strictly controlled through authorizations granted by regulatory authorities and are subject to a number of requirements including limits on potential doses to the public. In accordance with radiation protection principles, safety fundamentals and objectives, and the safety requirements

established in the IAEA Safety Standards, routine discharges to the environment are strictly controlled and managed to ensure the public and the environment are protected from harmful effects of these ionizing radiation sources.

Furthermore, radionuclide releases may potentially affect people and the environment outside the country in which the discharging facility is located. For this reason a number of legally binding international treaties addressing these issues have been negotiated. In Europe, one such instrument is the Convention on Environmental Impact Assessment in a Transboundary Context, otherwise known as the Espoo (EIA) Convention[3]. The contracting Parties of these legal instruments are committed, either individually or jointly, to take all appropriate and effective measures to prevent, reduce and control significant adverse transboundary environmental impact from activities that may lead to such discharges.

## Harmful Algal Blooms and Seafood Safety

Toxins derived from harmful algal blooms (HABs) can enter the marine food chain and may, in some circumstances, accumulate in seafood products to levels that affect human health. Consequently, they can adversely affect international trade, socio-economic systems and the sustainability of coastal fisheries, especially in developing countries, including the highly vulnerable, small island developing states (SIDS). To assist multilateral efforts to reduce the risks posed by HABs, the IAEA uses applied research and develops new methods involving isotopic and radio-isotopic approaches to assist Member States in managing marine resources and ensuring seafood safety. For more information access: http://www.iaea.org/monaco/page.php?page=2222 and http://hab.ioc-unesco.org/

3 http://www.unece.org/env/eia/eia.html which states that "The Espoo (EIA) Convention sets out the obligations of Parties to assess the environmental impact of certain activities at an early stage of planning. It also lays down the general obligation of States to notify and consult each other on all major projects under consideration that are likely to have a significant adverse environmental impact across boundaries".

## Pesticides and Biological Control Agents

Conventional pesticides for insect control play a crucial role in current agricultural production. However, their widespread application represents a serious concern for environmental pollution of agricultural and other ecosystems. Pesticides affect wildlife including beneficial, non-target insects, such as honeybees and other pollinators, as well as natural enemies of insect pests. The unintended effects on other wildlife can lead to consequential outbreaks of secondary pests. Pesticide use can also result in major pest resistance problems, and lead to residues in food and concern over human health effects.

Many alternative strategies are being developed and implemented as part of integrated approaches to dealing with major insect pests, infestations, microbes and moulds. However, the production and use of chemical and other insecticides is still high. These increases are happening especially in developing countries, where food consumption is growing at approximately five percent annually.

In response, the Joint FAO/IAEA Programme is involved in efforts to develop integrated insect control strategies, including the Sterile Insect Technique (SIT) to reduce the use of chemical insecticides. SIT relies on rearing the target insect in mass-rearing facilities, sterilizing one or both of the sexes, and then releasing the sterile insects over a target area in numbers large enough to outnumber their native, fertile kin. The use of conventional techniques in combination with SIT as part of an integrated area-wide intervention campaign can maintain a pest at a low prevalence level, or even lead to zones that are free of the targeted pests and require minimal control measures to sustain the pest-free territory. This provides the opportunity for more productive livestock and agricultural systems to be introduced without the need to expand the agricultural system into environmentally protected areas, while also reducing the amount of pesticides in the environment.

## Invasive Pests and Food Waste

With globalization, insect pests are moving to new areas of habitat. As a result of changing climate, they are also increasingly surviving in previously inhospitable areas. This is a major threat to food production for which strict quarantine laws are necessary to prevent insects from spreading from their native habitats to other countries and devastating agricultural production. The FAO/IAEA Programme is also developing irradiation quarantine treatments to ensure phytosanitary security and to mitigate the effects of invasive insect pests on food and agricultural production. To date, 14 treatments have been certified as global standards by the International Plant Protection Convention (annex to standard International Standard for Phytosanitary Measures (ISPM)28). These treatments were developed through activities through the Joint FAO/IAEA Programme.

Coordinated research activities are focusing on developing irradiation treatments that are applicable to both a wide range of different insect species (generic treatments) and those that are tailored for specific insect species. Current control methods rely on chemicals, which are being phased out because of their environmental impacts. One of the main chemical treatments is methyl bromide, a greenhouse gas, which is restricted under the Montreal Protocol because its presence in the atmosphere depletes the ozone layer. The use of irradiation is rapidly increasing because it is one of the few viable treatments that can render insects incapable of reproducing but with minimal impact on the quality of fresh produce (e.g. fruits and vegetables).

Nuclear techniques can also be used to reduce food waste as well as ensure the safety and quality of strategic food reserves. The FAO/IAEA Programme assists Member States to use food irradiation as an effective and safe treatment for reducing postharvest storage losses of staple and non-staple foods, ensuring food quality and reducing the risk of food illness.

Food irradiation can also be used as part of an integrated packaging and storage system to lessen the reliance on pesticides to protect crops.

## Mutation Breeding

The mutation of plants and animals is a natural process that drives evolution. It allows some species to thrive while others are pushed to extinction. As successful species evolve they tend to become specialists, adapted to very specific environments and interaction that are necessary for reproduction. This specialization, however, can also make them vulnerable to change, such as reduced precipitation or new diseases.

The FAO/IAEA Programme uses nuclear techniques and procedures to replicate the natural mutation process and identify new genetic variations that can thrive in a changing world. According to the Joint FAO/IAEA database, there are more than 3000 officially released mutant varieties in more than 200 plant species developed worldwide and grown on millions of hectares. The FAO/IAEA Plant

Breeding and Genetics Laboratory (PBGL) has been involved for over 50 years in mutation induction through nuclear techniques. The number of plant species subject to mutation inductions using Gamma-ray or X-ray mutagenesis continues to grow.

The mutants are either developed directly into varieties, or the benefits of induced mutant alleles in improving crop varieties are spread further through cross breeding. Once a major trait has been improved, the original mutant variety becomes a foundation variety and the trait is perpetuated in subsequent varieties.

The IAEA is actively supporting Member States with adaptation strategies based on mutation induction, mutant trait selection and efficiency enhancing biotechnologies that accelerate mutant line advances. Major activities are targeted towards fostering crop improvement (such as yield, quality, nutritional factors, market-preferred traits) as well as biodiversity protection. Climate-resilient mutant varieties can revitalise food production and rural development, particularly in developing countries, in an economically, socially and environmentally sustainable manner.

# Monitoring the Environment and Contaminants

To mitigate effectively any adverse impacts of development on the environment, IAEA Member States require timely and accurate data on the presence and behaviour of various substances, such as radionuclides, heavy metals, hydrocarbons and certain nutrients, such as nitrogen. This information is most frequently provided by local and national analytical laboratories. However, the IAEA also operates laboratories analyzing environmental contaminants in both terrestrial and marine environments, and builds the capacity of national laboratories when requested.

## Improving Capacity to Monitor Environmental Contaminants

When addressing pollution, whether radioactive or not, decision makers in Member States must have confidence that the information provided by their respective analytical laboratories is accurate. In this regard the IAEA provides Certified Reference Materials for various contaminants, both radioactive and non-radioactive. These have assigned values and uncertainties so laboratories in Member States can calibrate their equipment and check their analytical methods. For more information access: http://nucleus.iaea.org/rpst/ReferenceProducts/About/index.htm http://nucleus.iaea.org/rpst/ReferenceProducts/ReferenceMaterials/index.htm

Over the years, the IAEA has distributed thousands of samples of reference materials to laboratories around the world. In 2011, the IAEA saw a 30 percent increase in demand for these materials. This was in part related to the Fukushima accident in the same year, but was also due to the fact that as trade increases in a globalizing world, consumers demand certified proof that the food and products they purchase are safe for themselves and for their environment.

In order to meet this new demand, the IAEA is expanding its storage and dispatch facilities for Certified Reference Materials. Furthermore, the IAEA has to continually identify needs for future Certified Reference Materials, and to address the growing demands arising from new and emerging analytical techniques. This task is complicated by the fact that many laboratories do not use standardized methods, giving different values for the same material. Where possible, the IAEA produces Certified Reference Materials after optimizing and standardizing analytical methods.

The IAEA also oversees regular proficiency tests for the analytical laboratories of Member States. Interested participating laboratories receive samples to analyze, using their own equipment. The samples are prepared according to the request of the laboratories and the matrices are usually water, biota and soil type materials. The participating laboratories are requested to enter the results directly into a dedicated IAEA website, designed for the proficiency test schemes. They can check their laboratory performance within a week after the deadline. For more information access: http://nucleus.iaea.org/rpst/index.htm

In addition to working with individual Member States, the IAEA also collaborates with the United Nations Environment Programme (UNEP) in assisting a number of Regional Sea Conventions to build capacity in the analysis of radionuclides, trace elements, chlorinated pesticides, industrial chemicals and petroleum hydrocarbons in the marine environment, and to strengthen data quality assurance of national analytical laboratories involved in the respective marine pollution monitoring programmes. Examples include the Barcelona Convention (Mediterranean Action Plan), the Black Sea Commission (Black Sea Environment Programme) and the Kuwait Convention (Regional Organisation for the Protection of the Marine Environment of the Gulf). For more information access: http://www.iaea.org/monaco/page.php

## Environmental Monitoring Networks

The IAEA coordinates the international network of **A**nalytical **L**aboratories for the **M**easurement of **E**nvironmental **R**adioactivity (ALMERA). As a collaboration of existing institutions, ALMERA is a global network of analytical laboratories capable of providing reliable and timely analysis of environmental and food samples (i.e. soil, grass, vegetation, fresh water, drinking water, fish, milk) that could be contaminated in case of accidental or intentional release of radioactivity in the environment. Established in 1995, the network membership and activities have increased considerably. At the end of 2013 more than 140 laboratories from 81 countries were officially designated members of the ALMERA network. Due to regular participation in proficiency tests and trainings, the performance of the laboratories has been enhanced.

Several laboratories in the ALMERA network have become local centres of excellence, disseminating radio-analytical knowledge and skills, and currently this network plays a key role in constantly monitoring the environment. This collaboration expands the global coverage of areas that could be affected by contamination in case of radioactivity release in the environment. For more information access: http://nucleus.iaea.org/rpst/ReferenceProducts/ALMERA/index.htm

Since 1992, the IAEA has compiled measurements of marine radioactivity and in 2005 this database was made publically accessible through the Marine information System (MARiS) website. MARiS seeks to make marine radioactivity data more accessible and usable for research, education and policy makers. For more information access: http://maris.iaea.org/

## Food Safety

Nuclear related techniques are part of a wide range of analytical methods employed to monitor trace levels of pesticide residues and veterinary medicines in food and the environment. By leveraging its expertise and through its networks of expert institutes, the IAEA and FAO have successfully developed and transferred these technology packages, integrating bioassays/bio-monitoring screening tests and physico-chemical and isotopic

analytical methods for food and environmental contamination. The methodology is designed to provide feedback to food chain stakeholders in order to optimize the use of agrochemicals, avoiding unnecessary expenditure and improving both environmental sustainability and food safety.

Countries require alternative post-harvest pest control methods that avoid the use of potentially harmful chemical pre-shipment treatments, and many countries are now trading irradiated fresh fruit and vegetables in order to meet certified quarantine requirements for international trade. The IAEA's partnership with the FAO has taken a strategic approach to ensure that both the science and appropriate international standards are in place to support the commercial utilization of irradiation in this area. The quantity of irradiated exports is increasing because irradiation is proving to be a technically and economically viable option.

## Monitoring Radionuclides from Nuclear Facilities and Applications

All nuclear facilities and activities that undergo a licensing process must be carried out in accordance with all conditions specified in the authorization provided by a competent authority or regulatory agency. Compliance with the basic principle of radiation protection is mainly attained through the proper design of the nuclear facility, including the provision of reliable and efficient retention systems for radioactive materials and careful adherence to good operational procedures. Where controlled discharges are required and authorized, or when an accidental release occurs, an important and essential element is regular monitoring — both at the source of the discharge or release and in the receiving environment — to ensure the protection of the public and the environment.

Importantly, monitoring of radionuclides in the environment provides essential input for an assessment of radiation doses. The IAEA assists Member States to determine whether discharges to the environment remain below authorized limits and whether the resulting exposures to people, flora and fauna comply with radiological criteria. In addition to monitoring of discharges from current nuclear activities, the radiological characterization of inactive facilities and legacy sites is the basis for decisions on taking specific remediation measures necessary to ensure the safety of people living in those areas.

## Radioactive Waste and Spent Fuel Management

Waste that contains or is contaminated with radionuclides arises from a number of activities involving the use of radioactive material. The importance of the safe management of radioactive waste for the protection of human health and the environment has long been recognized, and considerable experience has been gained in this field.

The IAEA programme on Radioactive Waste and Spent Fuel Management provides support to Member States in establishing a proper safety and technology framework for the monitoring and management of radioactive waste and spent fuel. The IAEA Safety Standards, along with Safety Reports and IAEA Technical Documents, provide requirements and practical waste management guidance for wastes arising from the nuclear fuel cycle including transportation, storage and disposal.

The IAEA is the Secretariat to the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*. The Convention applies to spent fuel and radioactive waste resulting from civilian nuclear reactors and applications, and to spent fuel and radioactive waste from military or defence programmes. This Convention also covers if and when such materials are transferred permanently to and managed within exclusively civilian programmes, or when declared as spent fuel or radioactive waste for the purpose of the Convention by the Contracting Party. The Convention also applies to planned and controlled releases into the environment of radioactive materials from regulated nuclear facilities. The Convention calls for review meetings of Contracting Parties. Each Contracting Party is required to submit a national report to each review meeting that addresses measures taken to implement each of the obligations of the Convention.

## Managing Waste from Nuclear Accidents

Nuclear accidents, such as the accident at the Fukushima Daiichi NPP in 2011, bring into focus significant challenges related to the management of large volumes of radioactive waste, in the plant as well as in off-site contaminated areas. These challenges relate to short-term measures that were required to be taken at the NPP site after the accident and long-term measures for life-cycle management of all waste, on- and off-site.

Experiences and lessons learned in managing radioactive waste from past accidents (e.g. Chernobyl, Goiania) are documented in a number of IAEA publications. For more information access: http://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/WTS/decommisioning-Post-accident-documents.html

Considering the importance of this topic, and in line with activities defined under the IAEA Action Plan on Nuclear Safety that was promulgated following the accident at Fukushima, the IAEA has initiated work on compiling updated information on waste management for dissemination to the Member States. The relevant areas include characterization, treatment, conditioning, storage and disposal of radioactive waste generated as a result of nuclear accidents. This information will be helpful to the Member States in their understanding, planning and implementation of necessary measures for effectively dealing with potentially large volumes of complex waste streams that could arise in such situations.

# Environmental Remediation

Many non-nuclear industrial activities produce concentrated residues containing radioactive elements and other hazardous substances. Such activities include the extraction of coal, oil and gas; the extraction and purification of water; and the production of industrial minerals such as phosphates; and the mining and milling of uranium and of other metalliferous and non-metallic ores. Similarly, nuclear accidents or legacy nuclear facilities or sites may call for environment remediation. For more information access: http://www.iaea.org/OurWork/ST/NE/NEFW/_nefw-documents/Environmental_Remediation.pdf

## Setting the Baseline

Before starting remediation works, it is important to acquire baseline data on the level of radioactivity that exists naturally in the environment. With this information, researchers can quantify the effect of contamination and identify trends that could be occurring naturally in the environment. Baseline data also provides information for use in environmental impact assessments. In this context, the *Quantification of Radionuclide Transfer in Terrestrial and Freshwater Environments for Radiological Assessments*, commissioned by the IAEA, is a 600-page technical document representing input from 26 Member States over a six-year period. It has set a new standard for studying the environmental impact of industry and mining activities as well as of nuclear power plants and nuclear accidents.
http://www-pub.iaea.org/books/IAEABooks/8103/Quantification-of-Radionuclide-Transfer-in-Terrestrial-and-Freshwater-Environments-for-Radiological-Assessments

Similarly, the *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments* was published to assist Member States in environmental impact assessments relating to routine discharges of radionuclides to the environment.
http://www-pub.iaea.org/books/IAEABooks/8201/Handbook-of-Parameter-Values-for-the-Prediction-of-Radionuclide-Transfer-in-Terrestrial-and-Freshwater-Environments

In response to the needs of its Member States, the IAEA has published many reports covering various aspects of remediation of contaminated environments from safety requirements to remedial technologies that can be accessed at:
http://www-pub.iaea.org/books/IAEABooks/8874/Guidelines-for-Remediation-Strategies-to-Reduce-the-Radiological-Consequences-of-Environmental-Contamination
http://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/WTS/remediation-publications.html
http://www-ns.iaea.org/tech-areas/waste-safety/dischargeable.asp?s=3&l=18

## Building Capacity for Remediation

Since 2009, the IAEA has coordinated the Network on Environmental Management and Remediation (ENVIRONET, http://www.iaea.org/OurWork/ST/NE/NEFW/WTS-Networks/ENVIRONET/overview.html). This network supports organizations in IAEA Member States to avail themselves of relevant skills, knowledge, managerial approaches and expertise related to environmental management and remediation. It offers a broad and diversified range of training and demonstration activities with a regional or thematic focus. It provides hands-on, user-oriented experiences as well as disseminates proven technologies, and facilitates the sharing and exchanging of knowledge and experience among organizations with advanced environmental management and remediation programmes.

Dedicated e-learning materials are also available and a Wiki database has been created covering the different aspects of environmental remediation. These activities are supported by technical documents that cover policy and strategies, stakeholder communication and engagement, cost estimates, the assessment of the long-term performance, and life-cycle approaches.

## Remediation Technology

The IAEA has developed a ***Mobile Unit for Site Characterization*** that now is offered as a service to the IAEA Member States to support their activities in radiological characterization of sites in environmental remediation-related works. The service includes the detection of radioactive material in soils, interpolation and plotting of results with the aid of statistical and Geographic Information System (GIS) software, interpretation of results and provision of recommendations. For more information access: http://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/WTS/remediation-assistance.html

# Conclusion

The IAEA is the world's centre of cooperation in the nuclear field. It was set up as the "Atoms for Peace" organization in 1957 within the United Nations family. The IAEA works with its Member States and multiple partners worldwide to promote safe, secure and peaceful nuclear technologies. Its key activities contribute to international peace and security, and to global efforts focussed on social, economic and environmental development.

In this context, the IAEA is authorized to foster the exchange of scientific and technical information, as well as to encourage the exchange of training of scientists and experts in the nuclear field. The *nuclear science and technology* sector includes, among other things, the use of stable isotopes and radionuclides of natural origin, or from the nuclear fuel cycle, to study processes in nature and to protect the environment. The information derived from this scientific field of expertise can be used to inform decision makers of the environmental consequences of alternative management scenarios.

The IAEA advances and promotes the use of *nuclear science and technology* in order to:

- Investigate and understand the nature, sources, extent and movement of environmental pollution, both radioactive and non-radioactive;
- Investigate and understand both past and present environmental change;
- Limit humanity's impact and prevent environmental harm;
- Trace the source of vulnerable natural resources; and
- Observe and understand chemical and biological processes, as well as ecosystem structure.

As demonstrated in this publication, the range of applications available to the nuclear science and technology sector to support the environmental pillar of sustainable development is significant. The IAEA actively seeks to strengthen the environmental pillar though its technical cooperation programme, the Peaceful Uses Initiative, cooperative research projects, and strategic investment from the IAEA's Regular Budget.

The IAEA looks forward to building on the strong history of collaboration with its Member States to protect the natural environment and facilitate green growth.

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