In 2012, the Department of Nuclear Sciences and Applications (NA) laboratories in Seibersdorf will celebrate half a century of dedicated support to Member States.

The NA laboratories play a unique international role in supporting the use of nuclear science and technology through applied and adaptive research and development, scientific and technical services, and education and training. Over the years, the activities of the laboratories have continuously evolved in response to the ever changing landscape of nuclear technologies and applications, and the needs and interests of Member States.

The laboratories have come a long way. Starting with a mere 1736 m² of combined laboratory, office and corridor space in 1962, the original U-shaped building housed 14 professional and 24 general service staff. Today, it covers an area of more than 13 000 m² and is a dynamic hub for nearly one hundred scientists, technicians, fellows, visitors, interns and students from all over the world.

As we celebrate 50 years of success, it is an excellent opportunity to examine what must be done to build on our achievements, and to ensure the laboratories continue to evolve. Working with the world-class scientists in our laboratories, we are developing a plan for the modernization of the laboratories. This will be a long-term staged plan that will take into account the changing needs and interests of Member States and developments in science and technology. The goal will be to ensure the laboratories continue to be modern, fit-for-purpose facilities.

The wide range of activities undertaken at the laboratories in support of global development have benefited people all over the world. With a personal note of thanks to past and present scientists at the NA laboratories in Seibersdorf and to the numerous colleagues and stakeholders in Member States, we have collected some of the many success stories achieved over the years. I invite you to browse through the pages in front of you and to visit the Seibersdorf Laboratories.

Daud Mohamad
Deputy Director General
Department of Nuclear Sciences and Applications
Improving livestock reproduction efficiency in developing countries

It's a matter of economics: quite often, animals are a farmer’s most valuable assets, and the more offspring generated, the better the return on the investment involved in their feeding, management and housing. Farmers want their animals to have offspring regularly and, in most cases, work with livestock extension services and local veterinary services, relying on artificial insemination for breeding of ruminant animals.

Breeding an animal at the right time minimizes unproductive time in terms of number of offspring and/or milk production. In the case of dairy cattle, a cow can produce milk for 9–15 months after calving, depending on the breed, feeding and management system, but the amount of milk produced per day decreases after peaking during the first or second month. Thus it is critical to ensure that the animal is pregnant again as soon as possible, as gestation takes nine months. In addition, farmers want to control breeding cycles so that they can synchronize or organize to have all calves born at approximately the same time or to spread the births throughout the year, depending the availability of feeds. After insemination, the farmers also need to ascertain as quickly as possible whether the cow is pregnant, to minimize the time to reinsemination if the first procedure was unsuccessful.

Radioimmunoassay to measure the concentration of reproductive hormones

The FAO/IAEA Animal Production and Health Laboratory (APHL) has worked with partners for nearly three decades on developing, testing and validating radioimmunoassay (RIA) kits to measure and analyse an animal’s reproductive hormones, specifically progesterone to determine the optimal time for insemination. Recognizing the constraints of developing countries, robust kits were designed and validated for use under field conditions. These RIA kits require only small amounts of milk or blood and are carried out...

<table>
<thead>
<tr>
<th>LAB</th>
<th>Animal Production and Health Laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHALLENGE</td>
<td>Poor reproductive efficiency and low genetic quality of livestock</td>
</tr>
<tr>
<td>PROJECT</td>
<td>Improved reproductive efficiency and genetic quality of livestock</td>
</tr>
<tr>
<td>TECHNOLOGY</td>
<td>Radioimmunoassay; artificial insemination</td>
</tr>
<tr>
<td>IMPACT</td>
<td>More and better quality meat and milk</td>
</tr>
</tbody>
</table>

For smallholder farmers, livestock provide much more than milk, meat and eggs. They provide draught power for ploughing and transportation, manure that fertilizes soil, and hides and skins for the tanning industry, and they even serve as ‘living banks’ because they can be sold during periods of economic distress. Sustainable animal productivity is crucial for farmers’ livelihoods and for food security. In the case of cattle and buffalo, artificial insemination is often used to ensure both improved reproductive efficiency and more productive animals.

The FAO/IAEA Animal Production and Health Laboratory, working with partner laboratories around the world, has developed methods to improve the reliability of artificial insemination programmes and to shorten the intervals between calvings. These programmes are based on better timing of the artificial insemination to ensure better conception rates.
in test-tubes, so the animals are not in contact with radioactive materials, and the results are available after only a four-hour incubation at room temperature.

The work using RIA to monitor oestrous cycles, especially for dairy cattle and small ruminants, began in the early 1980s. Later, efforts focused on improving reproductive efficiency, combining diagnostic tests with field data to identify factors that limit productivity and to test, evaluate and implement remedial measures. The FAO/IAEA has identified and validated several strategies to assist artificial insemination programmes in diagnosing non-pregnancy within 22–24 days after insemination using RIA, instead of waiting the two to three months required by conventional methods like rectal palpation to confirm pregnancy.

FAO/IAEA adapted and validated two RIA assays that were suitable for measuring progesterone in samples from cattle, buffalo, sheep, goat, camels and camelids. It provided on-site training and regional training courses, tested and delivered the necessary equipment, and distributed progesterone kits to nearly 100 laboratories in more than 50 developing countries in Africa, Asia, Europe, Latin America and the Middle East.

This operation comprised two components, one supporting Member States in their breeding programmes and the other monitoring the results and using the feedback to further improve calibration and interpretation of results and other functions over the ten years that the project continued. One five year programme involving 14 Asian and Latin American countries analysed milk samples from 11 000 inseminations of 8 000 cows on 1 735 farms, and provided data that improved assay precision and led to higher conception rates.

Although other types of enzyme based assays have been developed in the interim, this procedure is still in use in many developing countries. Thanks to the training support that was provided along with the distribution of the kits, the work has become sustainable. Veterinary services and scientists who worked with FAO/IAEA on the process and the monitoring now have the capacity to collect and analyse samples and to provide advice to farmers, while private laboratories are now supplying the kits.
Study of sheep and goat genetics to improve disease resistance and increase productivity

Gastrointestinal parasites impose severe constraints on sheep and goat production worldwide and tend to affect developing and developed countries differently. In developing countries, parasitic diseases cause huge economic losses to sheep and goat owners, who are mostly poor or marginalized farmers and often cannot afford the veterinary care required to prevent or treat the diseases. For example, the economic loss to the Ethiopian meat industry due to parasitic diseases has been estimated at US $400 million annually. In developed countries where owners adopt modern animal production methods, intensely selected, high producing animals tend to be more susceptible to parasites and other diseases compared with indigenous breeds. At the same time, the emergence of strains resistant to drugs has further complicated the management of parasitic diseases in these countries.

Poor farmers in developing countries tend to keep small numbers of diverse indigenous breeds — breeds that adapt better to local conditions, often require less food, regularly produce healthy offspring, and most of all, have better resistance to local diseases. This wide and diverse gene pool of small ruminants available in developing countries provides an opportunity to identify and develop sheep and goat flocks that are genetically resistant to parasites and other diseases.

Thanks to advances in genetic sciences, it is now possible to quantify the level of host resistance and identify animals with genes for disease resistance earlier in their lives, using new generation genomic tools such as DNA markers. But first, researchers must identify which genes control...
which disease resistance. The FAO/IAEA Animal Production and Health Laboratory (APHL) is especially focused on developing such genomic tools so as to enable marker assisted breeding programmes for enhanced parasite resistance in small ruminants and to produce long term benefits to poor and marginalized farmers in developing countries.

**Mapping genes of economically important traits, including parasite resistance**

In order to improve the existing knowledge of sheep and goat genomes, FAO/IAEA has used nuclear technology to develop tools for mapping those genes responsible for economically important traits like meat and fibre production, wool quality, parasite resistance, etc. The construction of radiation hybrid (RH) panels by irradiating fibroblast cells with $^{60}$Co has helped to produce high resolution genetic maps that can serve as a link for comparison of traits across species. For example, an RH panel of goat developed by APHL is already in use by Chinese researchers who are mapping the genes responsible for reproduction and production traits. Similarly, HapMap mapping allows the genotyping of individuals of a species to generate comprehensive information on genetic variation. More than 40 research groups worldwide are using FAO/IAEA’s HapMap data on sheep to look at the genetic variations that affect meat productivity, wool quality, adaptability and disease resistance.

FAO/IAEA has developed the DNA fingerprints of several sheep and goat breeds across Asia to catalogue local genetic diversity. It has also established a network of global sheep and goat geneticists, sharing data across borders, which is especially important for research on trans-national breeds. Working with different countries, FAO/IAEA asked counterparts to select two breeds of indigenous animals — one susceptible to parasites, one not. These animals were artificially challenged with parasites to quantify their response and level of genetic resistance. Using modern molecular genetic tools, the differences in the level of resistance to parasites can be matched with the genetic variations detected in the animals to identify markers for parasite resistance. After validation, these markers can be used in marker assisted selection programmes to breed sheep and goats that have increased genetic resistance to parasites. In addition to helping poor farmers to improve their herds, this also means that indigenous animals, often overlooked in isolated rural areas of developing countries, now have the potential to make an important contribution to their distant relatives in the developed world.
Molecular techniques help identify strains of capripoxvirus in cattle, sheep and goats

The three species of capripox virus — sheep poxvirus, goat poxvirus and lumpy skin disease virus — produce similar symptoms. Until recently, it was assumed that only sheep had sheep poxvirus, only goats had goat poxvirus and only cattle had lumpy skin disease virus. When a herd developed the disease even after being vaccinated, as happened in Algeria in 2008, farmers assumed it was a vaccine failure or that the vaccine it not attenuated enough, rather than questioning whether the correct matching vaccine had been used.

But the real story is quite different. As researchers have learned in recent years, it is quite possible for any of three virus species to be present in sheep, goats or cattle. For example, a virus strain that was assumed to be a goat poxvirus because it was found in goats was found to actually be a sheep poxvirus, based on the full genome sequencing study that was carried out at the Animal Production and Health Laboratory (APHL). In 2007, as the three forms of capripox seemed to be expanding their reach and impact, the APHL, part of the FAO/IAEA Agriculture & Biotechnology Laboratories, initiated an international effort to find the real story through genome sequencing and gene amplification.

Gene based classification of capripox species
Because the three species of capripox virus circulate in different parts of the world, efforts to characterize the capripox pathogens included undertaking analyses of viruses from across geographical origins. Through genome and gene sequencing, scientists at APHL found two genes with markers...
specific to each capripox species. Based on those markers, they developed
genotyping tools for capripox species identification. Through field missions
and training courses, they are transferring these technologies to national
veterinary laboratories in Member States to help them to characterize their
local strains. The technologies have also been used in the quality control
of capripox vaccine, at the request of the Pan African Veterinary Vaccine
Center in Ethiopia, the African Union institution in charge of the control of
veterinary vaccines in Africa.

The work carried out at the APHL has shown the international community
that capripox viruses should not be classified using only the host
information of the virus. In fact, FAO/IAEA has suggested using gene based
classification and, in support, has provided cost effective tools that allow
the testing of animals for the presence of sheep poxvirus, goat poxvirus and
lumpy skin virus simultaneously.

Participants of a workshop on classical
and molecular veterinary virology working
on capripox virus differentiation assay.
Rinderpest eradication
THE BATTLE IS WON, BUT THERE IS STILL A WAR

On an epidemiological level, the story of rinderpest is a ‘case closed’. With worldwide fanfare in the spring of 2011, rinderpest, the historic cattle plague, was officially declared eradicated after a global campaign that eventually succeeded, in part because of improved tools introduced by the FAO/IAEA Animal Production and Health Laboratory (APHL). The tools, which were used to monitor the efficiency of the vaccination efforts, also improved the diagnosis of rinderpest outbreaks in the field and enabled authorities to take appropriate and timely steps to contain them.

But the case is not totally closed. Today, rinderpest virus samples still remain in many laboratory freezers, which poses the risk of accidental re-introduction of the disease or even its intentional introduction through bioterrorism. To avoid or limit this risk, FAO, the World Organization for Animal Health (OIE) and the IAEA are coordinating efforts to destroy the remaining rinderpest virus samples or to sequester them in secure laboratories. Together, they have formed an expert group on rinderpest (the so-called Joint Advisory Committee, or JAC) to catalogue those laboratories where the strains exist and to determine what, if any, further research should be conducted. Such research could help should similar diseases emerge in the future. For example, the human smallpox was eradicated in 1978; however, work continued on its strains, and what was learned has
been beneficial to the study of other pox viruses. In fact, current studies on capripox, which affects cattle, sheep, goats and wild animals, are based on smallpox research.

**ELISA technology contributes to success**

In the early 1960s, the international community initiated a global effort to eradicate rinderpest in Africa. When the programme ended 14 years later, it left one small pocket in West Africa and another in East Africa. From those two pockets, the disease re-emerged, expanding across the entire continent in the 1980s, killing millions of cattle. FAO/IAEA took lessons from the campaign of the 1960s and 1970s, noting that it had lacked the diagnostic tools necessary to monitor vaccination efficiency and to detect and surmount infections quickly, before they could spread. Thus, when a new rinderpest campaign began in 1988, FAO/IAEA called for introducing the newly developed nuclear related technology, the enzyme-linked immunosorbent assay (ELISA), and for including a quality control element within the rinderpest control effort, recognizing its valuable advantage in mass livestock disease containment strategies.

ELISA diagnosis is derived from radioimmunoassay, but instead of a radioactive tracer, it uses an enzyme and allows researchers to test up to 96 samples at a time. Its rapid diagnosis and cost efficiency proved to be a missing piece in the network’s efforts to control the disease. The last outbreak of rinderpest, in Kenya in 2001, was quickly controlled because it was diagnosed rapidly, thanks to the availability of specific and sensitive diagnostic tests, including the ELISA.

The 1988 eradication campaign also established a network to link the research and veterinary institutions of the countries where the disease threatened. Those institutions worked together for more than two decades and successfully brought an end to rinderpest. Today, the spirit of networking remains: there is no longer a single network, but instead, many networks are organized on a regional basis across Africa. With the support of FAO, OIE and IAEA, these veterinary laboratory networks have turned their attention to new areas and now respond to calls for the control of other transboundary animal diseases such as peste des petits ruminants, foot-and-mouth disease and African swine fever. FAO/IAEA continues to support the development and strengthening of animal disease diagnostic capacity in Member State veterinary laboratories, giving the networks the tools they need to meet the challenges of their new direction.

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**LEFT:** Rinderpest vaccination at the National Veterinary Institute, Debre Zeit, Ethiopia.

**RIGHT:** Declaration of global freedom from rinderpest in 2011.
Dosimetry Laboratory

Medical radiation machines must be correctly calibrated for accurate cancer treatment

Audit radiation dose measurement practices and resolve discrepancies

Thermoluminescent dosimeters (TLDs) in a postal dose audit service

Global increase in radiation dose accuracy; 1900 clinics can now trust their beam calibrations

For 115 cancer patients in a Latin American hospital, a radiation machine had offered rays of hope. Tragically, it turned out that the machine had not been calibrated correctly. Patients received such high doses of radiation that 42 died and the rest were left with lingering injuries. Safe and effective medical radiation therapy relies on precise measurement of the dose, known as ‘dosimetry’. Dosimetry can be compared to the way pharmacists make sure a medicine is the exact strength a doctor prescribes — it is a vital link between diagnosis and treatment. But the sensitive dosimetry equipment used to measure medical radiation beams is not always perfect, and its operators sometimes make mistakes. Recognizing this, the IAEA, in conjunction with the World Health Organization (WHO), has established an alarm system for medical radiation users that is designed to check hospitals’ dosimetry practices regularly and precisely. This dosimetry audit service, operated by the IAEA’s Dosimetry Laboratory, can alert radiation oncology clinics of the potential for danger before patients suffer the consequences of undiscovered mistakes.

IAEA/WHO thermoluminescent dosimeter audit for radiotherapy

ACCURATE DOSES FOR SAFE AND EFFECTIVE CANCER TREATMENT

Differences as small as 5 per cent from the intended radiation dose can change the outcome of radiation therapy. Without the patient’s or the doctor’s knowledge, a tumour may be left to grow, or a patient’s organs could be burned. The IAEA/WHO postal dose audit programme provides a simple service, free of charge, enabling hospitals to check their dosimetry practices.

Within this programme, the IAEA’s Dosimetry Laboratory (DOL) sends small dose-measuring devices known as thermoluminescent dosimeters (TLDs) to clinics, where they are irradiated as a patient would be. The clinics then mail the TLDs back to the IAEA, which can compare the radiation dose the hospital intended to give with what it actually gave. By aiming for perfection in dose accuracy, TLD audits help to eliminate risks.

To prevent mistakes in dosimetry from becoming radiation injuries, the IAEA alerts clinics when TLD audits find mistakes and asks them to repeat the test. If the second TLD audit does not show accurate results, a follow-up programme ensures that the clinic knows how to fix the problem and can do so effectively.

The IAEA/WHO TLD audit has found large numbers of poorly calibrated radiation beams since it began in 1969. Today, 95 per cent of audited clinics
reach acceptable accuracy. By comparison, in the 1970s and 1980s only half of all medical radiation beams showed acceptable dose levels. In fact, 11 per cent of therapy centres in those early years had dose deviations of more than 20 per cent.

The records of TLD audit results since the programme’s inception indicate a steady increase in hospitals’ abilities to get the dose right. But developments in radiation machine technology cannot take sole credit for this improvement. The global availability of accurate dosimetry checks made possible through TLD audits has contributed to this increase in accuracy.

More and more low- and middle-income countries now have the experts and equipment to support radiation oncology clinics. Most of the over 9000 radiotherapy beams that have been checked since the beginning of the IAEA/WHO TLD programme have been in these low- and middle-income countries. The IAEA/WHO TLD audit is crucial for enabling these countries to guarantee accurate calibration of their medical radiation sources.

The number of patients that might have been subjected to dangerously high doses without the IAEA/WHO TLD audit is impossible to determine. It is just as difficult to say how many people might have died of cancer because they did not receive enough radiation.

Either way, the TLD audit service run by the DOL has an impact that spans the world. In the 1900 hospitals in 130 countries that use the service, radiation oncology clinicians and patients can trust that the radiation beam calibration is correct, leading to accurate, reliable and effective treatment.
The International System of Units (SI) helps the world agree on units of weight and measures, making trade and information sharing easier and safer by ensuring, for example, that a kilogram of goods in China is the same as a kilogram of goods in France. The need to align doses of radiation used in medicine with international standards is just as important, but there is more at stake. Radiation can be harmful or fatal, either by overdosing healthy tissues or by failing to kill cancer cells when used for cancer treatment. Every radiation source therefore needs to be carefully calibrated through radiation measurements, known as ‘dosimetry’. But dosimetry cannot be carried out in isolation. It needs an external reference that can be trusted as a reliable radiation dosimetry standard. To address this need, the IAEA works with the World Health Organization (WHO) to disseminate dosimetry standards to a network of national standards laboratories known as secondary standards dosimetry laboratories (SSDLs). These SSDLs calibrate the dosimetry equipment that end users, such as hospital staff, then use to calibrate their machines. The IAEA’s Dosimetry Laboratory is the central laboratory of the IAEA/WHO SSDL network.

The IAEA/WHO SSDL Network
THE WORLD’S GUARDIAN OF RADIATION DOSE MEASUREMENT STANDARDS

Keeping strict standards for radiation medicine does more than prevent confusion. Because treating cancer requires the same dose in Africa as in Asia, medical physicists need access to accurate standards. Using the right amount of radiation means that they can make clear diagnostic X ray images without bombarding their patients with an excessive dose, or they can destroy a tumour without hurting healthy cells.

The IAEA’s Dosimetry Laboratory (DOL) adheres firmly to these strict standards and ensures consistency in radiation medicine. As the central laboratory of a global network of national standards laboratories, the secondary standards dosimetry laboratories (SSDL) network, it is the overseer of the dosimetry standards in Member States. By closely collaborating with institutions that establish the standards from first principles, such as the International Bureau of Weights and Measures (BIPM), it ensures that those who provide tools for radiation dose measurement are themselves operating accurately. Although the IAEA remains behind the scenes as a quiet guardian of dosimetry standards, its work has an ongoing impact throughout the world, enabling laboratories to identify improper equipment calibration in SSDLs and thus avoid causing harm to patients. For example, between 1982 and 1992, the IAEA found that 10 per cent of SSDLs had unacceptable deviations in their measurements. This was a serious problem, as it meant that hospitals using those SSDLs...
for calibration services may have adjusted their machines based on inadequate standards. The IAEA used this information to ensure more accurate calibration in those SSDLs. Today, 98 per cent of SSDLs have acceptable results, in part thanks to SSDL efforts to improve practices, and in large part thanks to the IAEA’s consistent standards dissemination.

As the world’s need for radiation dose standards changes, so must the SSDL network. The number of medical radiation machines is increasing worldwide, meaning that the SSDL network’s capacity must increase in parallel to meet the demand for dosimetry equipment calibration. The IAEA therefore supports its Member States in establishing SSDLs where possible. Since the late 1970s, the IAEA has set up or upgraded approximately 90 laboratories and trained their personnel through more than 170 projects. As an added benefit, valuable spin-off innovations in dosimetry technology have emerged from these projects, some of which are still in use today.

The reach of the IAEA/WHO SSDL network has grown from nine laboratories in 1976 to 85 SSDLs and six SSDL national organizations in 72 countries today. Many of these are in low- and middle-income countries that otherwise could not provide adequate metrology for end users of radiation on their own.

The number of times that the IAEA’s work has had a positive impact on the accuracy of a diagnostic X ray dose or the strength of a cancer-killing radiation beam may be impossible to know. But it is certain that the DOL’s steady hand of radiation standards can be felt every time a medical radiation machine is used.
In commercial food production operations, where hundreds, if not thousands, of animals are reared in small spaces, disease can pass quickly from animal to animal. Thus, it is an accepted procedure for food production companies to use antibiotics at a low level to prevent — rather than treat — bacterial infections. Problems arise when proper controls are not taken and producers or farmers use too much or the wrong antibiotic. These veterinary drugs can build up in the animal’s tissue, become part of the food chain and potentially prove harmful to consumers.

This was a serious problem in Sri Lanka, where small producers saw commercial producers using antibiotics and getting higher prices for their products. In the early 2000s, it was easy to buy antibiotics and other veterinary drugs in Sri Lanka, with no control over their use. Thus, many individual farmers used veterinary drugs, thinking that they were increasing the value of their products, but with no understanding of the need for strict control of the drug choice and dosage.

In 2002, the Government of Sri Lanka asked the FAO/IAEA’s Food and Environmental Protection Laboratory to help with the design and development of a laboratory that could provide chemical analyses of animal and aquaculture products — including shrimp, chicken and dairy products — and also train staff. The decision was made to set up the laboratory on the campus of the University of Peradeniya, providing equipment and training staff to test for residues of veterinary antibiotics and microbiological contamination. Today, that laboratory’s services are being utilized by the local shrimp and poultry industries and by Sri Lanka’s regulatory authorities. It has proven so successful that the Government has added a new building not only to provide testing services but also to serve as a teaching laboratory, where university students can study for a master’s degree in food safety.
Choosing the university as the location proved to be astute. FAO/IAEA transferred a series of tests for veterinary drugs using qualitative microbial inhibition assays and enzyme-linked immunoassays specifically adapted to meet the needs of Sri Lanka. The tests were transferred from the FAO/IAEA Laboratories in Seibersdorf, Austria, and validated in the Sri Lankan laboratory, with FAO/IAEA also providing training in the technology.

Private sector funds food control laboratory

When the laboratory opened in 2004, it proved especially important to the aquaculture companies that needed certification of their products in order to trade their shrimp internationally. Having the laboratory proved so helpful that, today, the majority of the laboratory’s funding comes from the exporting companies themselves. These companies are willing to pay to ensure the sustainability of the laboratory services they require. The laboratory also supports small producers who sell on the local markets, giving them guidance on the safe use of veterinary drugs so that they also can provide certification of food quality. In fact, the small producers came up with the idea of labelling their products with safety assurance seals, which has proven to be a boon in local supermarkets.

The laboratory itself has proved so successful that the Sri Lankan Government has added a new laboratory building that is now used both for testing food products and for teaching courses on food safety. Not only does this laboratory provide a service to the food industry and national regulatory agencies that rely on it for testing, it also offers a master’s degree in food safety to students, who are then primed to become laboratory staff — all of which, in turn, contributes to the laboratory’s sustainability.

In 2011, the laboratory received accreditation under the International Organization for Standardization (ISO) quality system, which means that its work is now certified at the highest global level. Having food safety controls in place using a laboratory with this level of certification means that Sri Lankan consumers can shop with confidence that the food in the local markets is safe and that the commercial food producers face no barriers when they offer their certified production on the global markets.
Panamanian food control laboratory uses satellite centres to improve link to farmers

When Panama’s Ministry of Agriculture (MIDA) embarked on establishing a national food control laboratory, it started by building a simple, unadorned structure near Panama’s main airport. That structure has now been staffed and equipped and is playing a critical role in Panama’s food control system, thanks to the support of the FAO/IAEA’s Food and Environmental Protection Laboratory, which worked with MIDA in determining which instruments were needed for tasks such as screening residue levels of chemical pesticides in fruits and vegetables. In 2006, as the laboratory was equipped and inaugurated, MIDA established satellite screening centres in rural areas. These centres have raised farmers’ awareness of the regulations related to chemical pesticide use and have provided a link between the farmers in the field, the regulators and the market.

The laboratory is a key part of Panama’s broad food control system, which also includes a risk control authority, a regulatory infrastructure and a national information system to keep farmers and producers advised of emerging or changing regulations. Before the national monitoring plan was established, there was no effective control over pesticide management practices in Panama, and therefore no control over the chemical residues that remained on the produce. This constituted a health threat to consumers and a financial risk for producers with regard to their ability to meet stringent international requirements concerning residue limits in foods for export.
Laboratory takes a proactive role

Within three years of the laboratory’s launch, the increasing number of samples being brought for analysis indicated that the monitoring plan implemented around the country had gained acceptance and respect. With ongoing support from FAO/IAEA in terms of training and equipment improvements, the laboratory has taken a proactive role in the agricultural sector, preparing manuals and guidelines promoting good agricultural practices (GAPs) for farmers. MIDA is in the process of designing Panama’s checklist for GAP compliance. This will enable farmers to request to be audited, and if they comply, their good practices will be certified.

In all of this, the laboratory plays a central role that is essential for end-use testing for unsafe levels of chemicals in fruits and vegetables. But the laboratory also has a key role to play at the front end by providing risk assessments and data directly to regulators and decision makers that they then can factor into Panama’s regulations and GAPs, helping to prevent problems before they occur.

Through its outreach to the agricultural community, which also includes working through the extension system, the laboratory and its inconspicuous small huts scattered throughout Panama — the satellite screening centres — facilitate continuous improvement of Panama’s agricultural production system. Pineapple, for example, is one of Panama’s major exports, and the pineapple industry now depends on the laboratory to provide certification that pineapples produced in Panama comply with international standards. When the laboratory was established in 2006, Panama exported US $12.5 million in pineapple annually. By 2011, that number had more than doubled to US $26 million. In addition, the country went from 1.4 million hectares to 2.4 million hectares of planted pineapple, indicating that both the local producers and the foreign importers recognize the quality of Panamanian products and the importance of the service that the laboratory provides.
Mitigating pesticide contamination in Colombian lake and food chain

The setting is Lago de Tota, a large lake in Boyacá, Colombia, surrounded by exceptionally fertile land where many small farmers grow onions as a cash crop. The farmers also protect their crops from pests with chemical pesticides. The problem is that the fields lie on hillsides, and when it rains, the chemicals run off of the land and into the lake.

The effect of contamination from the agricultural chemicals in the area is visibly obvious — a decrease in the lake’s fish population, an increase in birth defects and disease, children with dermatological problems on their hands and feet — all most probably caused by dangerous levels of chemicals entering the crops, soil, groundwater and the lake, and through this, the food chain.

Since 2006, the FAO/IAEA’s Food and Environmental Protection Laboratory has supported a regional project that includes laboratories from 14 Latin American and Caribbean countries that work together, sharing information on approaches to assessing the impact of pesticide contamination on food and the environment. Instead of monitoring the individual commodities growing in the fields, participants monitor the environmental aspects that affect, or are affected by, what happens in those fields.
Teaching laboratory now fully accredited
What is today Colombia's Pesticide Residues Analysis Laboratory (LARP) began as a teaching laboratory at the National University of Colombia. With support from the FAO/IAEA, it has consistently upgraded both staff skills and equipment, and is now fully accredited and a participant in the regional project studying the environmental impact of agrichemicals. For LARP, this has included looking at residues of pesticides in soil, water and food, in situations such as those occurring in the onion fields of Lago de Tota.

In addition to the subjective estimation of pesticide contamination in the lake, LARP researchers conducted scientific tests of the lakesides environment to pinpoint both the sources and the environmental impact of the agrichemicals, using radiotracers to investigate whether the soil was absorbing the pesticides and, if so, how much. This required taking samples from several spots in the area, mixing them together and then taking samples from that mix to test in the laboratory.

The results of the tests have provided the science based data needed to initiate a communication campaign, informing farmers about the consequences of inappropriate pesticide applications and introducing them to better farming practices. LARP found that because this pesticide contamination affects farmers, fishers and consumers, albeit in different ways, all were willing to work together to seek solutions.

For example, the project recommended a software package that rates pesticides in terms of their mobility through surface or groundwater and their toxicity to organisms such as fish. Using models that incorporate soil composition, water flow, wind and other variables, the software determined the probability of dangerous levels of certain pesticides ending up in the groundwater or in the lake. Thus, the researchers were able to predict which pesticides were most or least likely to end up in the groundwater or the lake, and to advise farmers to use those that posed the least danger.

Today, thanks to the efforts of LARP, the National University of Colombia has made Lago de Tota a study area for the entire country, sharing results of the improved agricultural practices introduced there. Studies conducted since introducing the new practices indicate that the water running into the lake is less contaminated and, because farmers have modified the types of pesticides they use, the chemicals that do enter the water are much less likely to persist for long enough to enter the food chain.
Laboratories in 12 countries work globally to strengthen pesticide management approaches

When the FAO/IAEA’s Food and Environmental Protection Laboratory (FEPL) announced plans for a project in which laboratories around the world would work jointly to analyse approaches used in pesticide management, more than 50 laboratories applied. In the end, FEPL selected 12 laboratories from 12 countries, with each laboratory, in turn, selecting a micro-catchment area where it would set up its analysis and monitoring activities.

The micro-catchments, small geographical areas with a limited variety of land uses, became the project’s living laboratories. Although the 12 catchments varied from country to country in terms of land use, soil, hydrology and weather conditions, a set of harmonized protocols and techniques, both nuclear and traditional, were developed for studying the impact of pesticide and agricultural management practices on the environment. The laboratories set up multidisciplinary teams, including a core of analysts and technicians, but also geographers, biologists, soil scientists, statisticians and social scientists.

**Monitoring gives snapshot of chemical impact**

FAO/IAEA supported the project and helped develop methodologies that incorporated simple and inexpensive screening methods, which, in turn, greatly reduced the number of samples that required the more expensive high-tech, nuclear related methods. They also adopted biomonitoring, which calls for cataloguing the macro-invertebrates that are present in or next to rivers or lakes. The ability of these macro-invertebrates to survive in the...
waters is a good sign of the health of the water, indicating, for example, high levels of chemicals or low levels of oxygen. This type of monitoring gives a snapshot of the impact a chemical has on living organisms.

The advantage of having 12 analytical laboratories working in parallel, comparing and combining the results of their monitoring and assessment efforts, was seen in particular in the on-the-ground changes in agricultural practices in participating countries. At the farm level, for example, growers have now learned to set up buffer zones and to plant cover crops to concentrate chemicals and keep them from leaching. As the participants have worked together, sharing and integrating the methodologies they use in the field, the improvement in their analytical capabilities has been recognized, and they report that both government officials and the private sector increasingly seek them out for advice and feedback.

To encourage ongoing dialogue and to expand upon what has been learned from the 12 laboratories working together, the project established a clearly defined network along with a dedicated web site, maintained by the participants, which has the potential to become a global forum for all laboratories interested in promoting food safety along the farm-to-fork food chain.

With this kind of cooperation, it is not just one development at a time, one change at a time or one country at a time. It is all pulling together for the big picture. The participants focused on both bottom-up and top-down communication. They agreed that it is just as important to communicate with decision makers as it is with farmers. The laboratory results and data help decision makers to develop and improve national regulations for good agricultural practices, and farmers gain from the practical, science based suggestions for improving their pesticide management on the ground. It is proving to be a most promising approach.
Tsetse flies have a reproductive biology totally different from that of most insects, feeding only on blood and not laying eggs. The female keeps the larvae in her uterus, feeding them through milk glands and releasing one at a time every nine days. The FAO/IAEA Insect Pest Control Laboratory was instrumental in adapting the sterile insect technique (SIT) for use against the tsetse fly. To achieve this, FAO/IAEA developed new methods for rearing, feeding, sterilizing and releasing the male flies, including feeding them on blood located under membranes rather than on live animals.

When an insectary was established on the United Republic of Tanzania’s mainland to mass rear the flies, it was necessary to collect the blood needed for feeding them from local abattoirs, and then to decontaminate it from bacteria. This was done with gamma radiation, using the same radiation chamber used to sterilize the male flies.

Other campaigns on Zanzibar had tried tsetse eradication over the years, using combinations of traps, ground spraying or covering livestock with an oil-based ‘pour-on’ insecticide, but the fly population always rebounded. It was only after FAO/IAEA added the SIT, with sterile males having the drive to find and mate with the remnant wild females, that the tsetse was finally eradicated from the island. At the height of the eradication campaign on Zanzibar, 110 000 sterile flies were released each week over the island.

The last wild female tsetse fly was trapped in 1996. While monitoring continued for another three years to ensure that the tsetse fly had indeed
been eradicated and disease transmission had stopped, the benefits of the eradication campaign began immediately. Within five years, milk production tripled, as did the number of farmers keeping cattle for farming and transport.

**Tsetse trail of damage**

Tsetse flies (there are up to 30 species) are found only in Africa, where each year they are responsible for US $1 billion in direct losses due to decreased milk and meat production and animal deaths. They also cause US $4–5 billion in indirect losses, because even where not fatal, the trypanosomosis infection weakens farm animals so that they are no longer able to produce or provide draught power for farming and transport. The form of trypanosomosis that affects humans, known as ‘sleeping sickness’, is almost always fatal if not treated. In the 1990s, some 500 000 people were infected at any given time, with 40 000 new infections every year.

FAO/IAEA now offers packages to support eradication campaigns in other countries that include guidance on baseline data collection, feasibility studies for eradication campaigns based on geographic information systems that pinpoint areas where the target species exist, and detailed land use plans to guide sustainable utilization of natural resources after removal of tsetse flies. In addition to rearing technology, the package incorporates insect population genetic techniques to assess whether target populations are sufficiently confined or even isolated from neighbouring populations, as this will reduce the risk of re-infestation and increase the probability of sustaining the eradication status.

FAO/IAEA is assisting several West and East African countries in introducing this integrated approach to tsetse fly eradication. Noting Zanzibar’s success, the African Union has called for eradicating tsetse flies from Africa. The success also has generated hope for support of other neglected tropical diseases that affect primarily poor people in rural Africa.

**Sterile insect technique (SIT)**

The SIT is a type of birth control for insects that involves the mass rearing and sterilization of large numbers of male insects by subjecting them to ionizing radiation. The sterile insects are then released systematically over infested target areas, where they mate with fertile wild females of the pest population but produce no offspring. If sterile males outnumber wild males, the wild population declines and can eventually disappear.
The future success of the tsetse fly eradication campaign in Ethiopia depends on having an insect raising facility, known as an insectary, with the capacity to hold colonies of 7–10 million female flies that produce at least 700 000 excess male flies a week. As part of the process, these excess males are sterilized using gamma radiation and released by aircraft over the target area – in this case, the Southern Rift Valley, where infestation by the deadly flies has impacted the area’s agricultural potential.

Thus, when an unknown malady began to affect the reproduction of the flies being reared in the laboratory during the start-up phase of the Ethiopian operation, it was a serious setback. After extensive testing, the FAO/IAEA Insect Pest Control Laboratory diagnosed the cause as a virus that affects the salivary glands of the tsetse fly. As a next step, FAO/IAEA established a consortium of international scientists from 15 countries to develop strategies for managing the virus that would enable maintenance of tsetse fly colonies large enough to support an SIT component within Ethiopia’s tsetse fly eradication programme.

In studying the virus in the rearing colony, FAO/IAEA found that it was transmitted from mother to offspring, but that it also spread through the insectary’s feeding system. Because tsetse flies feed only on blood and normally bite through the skin of their victims, the laboratory had designed shallow feeding trays with a thin membrane stretched like skin over the top, which the flies punctured to reach the blood below. It turned out that using
each tray for multiple feedings increased the chances of virus spread in the colony.

**Study of virus DNA leads to treatment**

The genetic characterization of the virus indicated that its DNA multiplication was similar to that of the herpes virus in humans. With this knowledge, FAO/IAEA screened several antiviral drugs used to treat herpes, identified one that could control the virus and added it to the feeding regimen. The laboratory also modified the membrane feeding protocol, reducing the number of feeding cycles per membrane to reduce fly-to-fly transmission.

Additional research on the virus itself found that it did not match any existing virus group. Thus, FAO/IAEA proposed it to the International Committee on Taxonomy of Viruses, which agreed that it was indeed a new family and gave FAO/IAEA the right to name it. The name chosen, *Hytrosaviridae*, derives from the Greek for ‘hypertrophy of salivary gland’.

When the tsetse fly spread in Ethiopia from the river valleys into higher elevations, apparently as a result of changes in the climate, farmers retreated to the hills, abandoning their fertile land in the foothills to escape the flies and the disease they carried. With support from FAO/IAEA, and in part thanks to the identification and management of *Hytrosaviridae*, aerial releases of sterile male tsetse flies began in 2012, with plans to gradually expand the SIT component of the eradication campaign to the entire Southern Rift Valley area of Ethiopia. Success will enable Ethiopia’s farmers to return to their traditional lands and to farm in some of the lowland valleys.

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Today, with the global trade in agriculture products booming as never before, plant pests and diseases are increasingly endangering food production and food security. Not only is their control important to maintain yields in individual fields, but it is also critical to national economies that benefit from valuable export crops such as fruits and vegetables. For example, many importing countries will not accept shipments of fresh fruits and vegetables from countries where the Mediterranean fruit fly (medfly) is present, even in small numbers.

The willingness of countries such as Argentina, Chile, Guatemala, Mexico and Peru to establish the mass rearing factories and related infrastructure needed to release billions of sterilized male medflies, and to undertake logistically complex area-wide pest control efforts of such a magnitude, indicates how important medfly eradication is to those countries whose economies are based on crop export, especially in view of the growing international demand for fresh fruits and vegetables year-round.

**Improving efficiency in SIT methods**

Over the years, the FAO/IAEA Insect Pest Control Laboratory has promoted the SIT as part of a portfolio of pest control methods. It has proven to be the method that provides the ‘knockout punch’ needed to culminate eradication efforts.
efforts. FAO/IAEA continually works to improve both the technologies and the equipment used for breeding, sterilizing, feeding and releasing the insects, and adapts the methods used to meet national needs and ecological conditions according to the specific insect being controlled.

For the sake of efficiency in the factory as well as in the field, the rearing process must produce both males and females in order to maintain the mass rearing colony, and it must produce enormous numbers of ‘excess' males for release in the field. This is where ‘genetic sexing' comes in. Genetic sexing is used to separate males and females on a very large scale. In collaboration with its research partners, FAO/IAEA has developed breakthrough procedures for genetic sexing, including one that lowers the temperature sensitivity of the females when they are still at the egg stage. Male and female eggs collected from cages are put in water that is heated to 34°C, which will kill all the female eggs, and thus only males hatch. This means that no effort or money is wasted rearing or transporting females, which are not needed for the release process. In addition, in the absence of sterile females in the field, sterile males do not waste their limited sperm on sterile females, thereby significantly increasing SIT effectiveness.

Setting up SIT activities in a country is not a one-off proposition. FAO/IAEA continually improves procedures to make them more efficient and cost effective. The care taken in developing the processes has paid off, with benefits worth billions of dollars to countries such as Argentina, Chile, Guatemala, Mexico and Peru, which have eradicated their medfly populations from all or parts of their territory, and now are able to export their fresh produce anywhere in the world.

**Sterile insect technique (SIT)**

The SIT is a type of birth control for insects that involves the mass rearing and sterilization of large numbers of male insects by subjecting them to ionizing radiation. The sterilized insects are then released systematically over infested target areas, where they mate with fertile wild females of the pest population but produce no offspring. If sterile males outnumber wild males, the wild population declines and may eventually even disappear.

**Insect Pest Control Laboratory**

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Mexico overcomes fruit fly pests by combining two environmentally friendly pest control methods

Not to be confused with a parasite, a parasitoid insect is one that attacks another insect by stinging and thereby laying eggs in it. In recent decades, parasitoids have gained favour as a natural, environmentally friendly way to control insect pests in the field. Instead of using harmful chemical insecticides, pest control programmes send out a bevy of parasitoids that destroy the pests’ larvae. Although a process with great potential, it also requires a great deal of monitoring to ensure that the parasitoid wasps will act as expected once they leave the mass production facilities and enter agricultural fields. It is an ongoing cycle: when the wasps find the infested fruit, they sting and lay eggs in pest larvae, not only killing the pest, but eventually the wasp eggs hatch and the new wasps go forth to sting and destroy other fruit fly larvae.

For more than a decade, the FAO/IAEA Insect Pest Control Laboratory has worked with counterparts in Mexico to develop an integrated pest management approach to control fruit flies in its fields and orchards, one that combines the use of the sterile insect technique (SIT) with the controlled release of parasitoid wasps. The work has been done at two adjacent mass rearing facilities in southern Mexico: one produces 50 million parasitoid wasps a week, and the other produces several hundred million sterile fruit flies each week.
This industrial rearing complex has also enabled a genetics laboratory to take advantage of the insects available in the rearing facilities to screen for markers that can be used in genetic sexing — that is, pinpointing genes that determine the sex of insects while they are still in the development stages. With this method, geneticists have developed a system that enables the separation of male and female Mexican fruit flies, which makes the release processes cheaper and, in the absence of sterile females, makes the sterile males more efficient in the field.

**Extra precautions taken**

For parasitoid production, the fruit fly larvae are sterilized before wasps are allowed to lay their eggs in them, because only 70–80 per cent of the larvae are actually stung by the wasps. This means that, if the larvae are not sterilized, there is the possibility that they will develop into fertile fruit flies. This has no impact on the wasp, but it ensures that those larvae that are not stung and that actually develop into fruit flies will be sterile and thus can do no harm.

The success of this process, which uses parasitoids in combination with the SIT, can be seen across Mexico, where an area equal to half of Mexico’s territory — 1 million square kilometres — has been declared free of, or with a low prevalence of, Mexican and West Indian fruit flies. As a result, the fruit industry in northern Mexico has expanded significantly, creating thousands of rural jobs and reducing crop losses and environmental contamination. The US state of Texas, which borders Mexico, has also joined this campaign and adopted this method of pest control.

**Sterile insect technique (SIT)**

The SIT is a type of birth control for insects that involves the mass rearing and sterilization of large numbers of insects by subjecting them to ionizing radiation. The sterilized insects are then released systematically over infested target areas, where they mate with fertile wild females of the pest population but produce no offspring. If sterile males outnumber wild males, the wild population declines and may eventually disappear.
In the 1980s and 1990s, the increasing number of Mediterranean fruit fly (medfly) outbreaks was threatening to wreak havoc on California's extremely valuable fruit and vegetable crops. California controlled the outbreaks mainly with recurrent aerial spraying of pesticides, often in urban areas. However, the pesticides wafted onto people, their properties and cars, resulting in increasing public opposition and lawsuits in view of real or perceived side effects. In 1994, the FAO/IAEA Insect Pest Control Laboratory recommended an area-wide sterile insect technique (SIT) programme to cover the entire 6,475 square kilometres of the Los Angeles basin, involving the weekly release of several hundred million sterile fruit flies, an approach that resulted in eradication. In fact, the programme proved so successful that preventive releases have continued since then over areas at high risk of invasion, using an FAO/IAEA strain and other technologies. Outbreaks and the cost of the programme have been reduced, and the area-wide preventive releases have kept California free of this pest to this day. The state of Florida, another major US fruit and vegetable producer subject to recurrent medfly outbreaks, adopted the same approach, with similar success.

Southern California is one of the world’s most important producers of horticultural crops. Until the initiation of an area-wide sterile insect technique (SIT) eradication campaign in 1994, it fought a constant battle against this extremely destructive fly — efforts that often did not achieve the sustainable eradication they sought. However, the area-wide SIT campaign, which released over 400 million sterile male flies a week, was so successful that California has continued with a preventive SIT release programme ever since, recognizing that with the movement of people and cargo, introductions of medflies cannot be completely avoided. With SIT application, any medflies introduced into high risk areas will be surrounded by sterile males and thus will be unable to reproduce, making the approach highly successful.
The preventive programme maintains extensive monitoring networks to ensure immediate detection of any invading fertile females. Initially, however, the traps attracted both male and female flies. Even though the sterilized males were marked with a fluorescent colour, it was virtually impossible to spot a single introduced wild fly amid sometimes tens of thousands of recaptured sterile flies. With the transfer of an FAO/IAEA strain that includes genetic markers and allows the release of only sterile males, combined with the development of a new lure that attracts females to a special food odour, it became possible to redirect the state-wide trapping networks into a much more effective system focused mainly on the detection of females.

Sterile male insects normally are not equal to wild males in their performance, because they are reared in a protected environment and are subject to a series of procedures, including sterilization through radiation, before their release. Yet these sterile males must be in good form if they are to compete with wild males to get the attention of and to mate with any females that happen to be in the area. Research to determine how to make these males more attractive during courtship found that females prefer males with an aroma of ginger root oil, and thus called for factoring its aphrodisiac scent into the medfly pre-release process as an ‘aromatherapy’.

While from the outside, such enormous efforts to develop and apply medfly aphrodisiacs and other technologies may seem extreme, the work has had outstanding results. The preventive approach has proven significantly less costly than what had been spent annually on the recurrent emergencies and reactive aerial spraying of pesticides to control the outbreaks. It also raises no public opposition in terms of real or perceived side effects of chemical residues on crops, health issues for citizens or spots on the paint of automobiles.

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Controlling fruit flies

REPLACING INSECTICIDE BASED MANAGEMENT OF PEST FRUIT FLIES WITH A BIOLOGICALLY BASED APPROACH

The sterile insect technique (SIT), when combined with other control methods, has proven extremely successful in countries where it has been used to eradicate fruit fly populations. However, after the initial success, trapping networks need to be maintained to detect re-introductions, as there is always the threat that the pest will return in infested fruit in spite of strengthened quarantines. After all, fruit fly eggs or larvae in fruit are only a few millimetres long, and as people and agricultural products move across boundaries, these pests can move with them, undetected.

Traditionally, governments established the infrastructure required for SIT application, including the mass rearing and sterilization facilities required to produce millions if not billions of fruit flies per week. There was no bottomline incentive for the private sector to invest in building and operating facilities to meet a goal of pest ‘eradication’. After all, true eradication means that there will no longer be a need for the facilities and thus no return on the investment. Because of the constant threat of re-infestation, setting a goal of ‘permanent suppression’ of a pest population is often more realistic. This has made investment more attractive to commercial biocontrol companies, because they can rely on the continuous demand for sterile insects and related services.
However, the increasing shipment of sterile fruit flies between suppliers and users brings with it the need for internationally accepted quality control procedures to determine which shipments fulfil minimum standards, and which sterile fruit flies perform well and which do not. In response, FAO/IAEA and the United States Department of Agriculture collaborated on producing a manual to guide governments and biocontrol companies that buy or sell sterile insects.

SIT programmes have traditionally used mainly ionizing radiation based on gamma rays to sterilize insects, but increasing concern about the machines falling into the wrong hands has meant increased limitations for their purchase, transport and use. FAO/IAEA has worked with both public and private sector partners to develop an insect sterilization chamber that works with X rays rather than gamma rays. These new machines have the same simple regulatory requirements as machines used to scan baggage at airports, and have no special safety precautions for shipping or disposal costs at the end of their useful life. In addition, the cost of using the machines is only incurred during the time they are connected to the grid, while isotopic decay of gamma chambers is continuous and fixed replacement intervals are required regardless of their use.

Thanks to the ongoing technical advances that have come from FAO/IAEA, the SIT is recognized as an environmentally friendly and cost efficient technology when applied routinely on an area-wide basis to manage fruit fly populations, especially when compared with reliance on pesticides to suppress them. FAO/IAEA has successfully transferred the technology to Brazil, Croatia, Israel, Jordan, South Africa and Spain, among other countries. Adoption of the SIT means that farmers and their families avoid exposure to chemical pesticides and that they can export their insecticide free fruit at a premium. The current possibility of outsourcing production of sterile insects to the private sector also means increased SIT uptake, efficiency and sustainability.

**Sterile insect technique (SIT)**

The SIT is a type of birth control for insects that involves the mass rearing and sterilization of large numbers of male insects by subjecting them to ionizing radiation. The sterilized insects are then released systematically over infested target areas, where they mate with fertile wild females of the pest population but produce no offspring. If sterile males outnumber wild males, the wild population is suppressed in an environmentally friendly way.
As the world of nuclear technology continues to leap forward, with advances in instruments crucial in areas such as medicine, agriculture and power, it is also important that those with responsibility for maintaining and repairing such instruments advance in parallel. Many developing countries face serious problems due to lack of adequate technical infrastructure and skilled personnel to operate and calibrate nuclear instruments or repair them if necessary. Each year, the IAEA’s Nuclear Spectrometry and Applications Laboratory offers training courses, workshops and fellowships to scientists from developing countries to help them establish nuclear competencies in their countries and then ensure that they have the skills needed to keep the equipment working properly.

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Every year for the past 25 years, ten scientists from developing countries have journeyed to the IAEA’s Nuclear Spectrometry and Applications Laboratory (NSAL) in Seibersdorf, Austria, 40 kilometres outside Vienna, for a six month training course on the maintenance and repair of diagnostic and analytical nuclear equipment. The course was established at the request of IAEA Member States whose laboratories had received high-tech equipment from the IAEA or other donors. While they had also received basic training in how to operate the equipment, they often encountered problems that were beyond what that basic training offered.

The range of equipment the countries have is quite broad — from gamma cameras used in medical diagnostics to radiation chambers used in food quality control laboratories. Yet all of that equipment was designed for industrialized countries with reliable electric mains and power grids. Manufacturers do not account for the fact that customers in developing countries often lack reliable power systems and face incessant power cuts, brownouts or surges, nor do they consider the impact of extreme storms that affect not just people in their homes, offices and schools, but also laboratory equipment that can be damaged or even destroyed as a result of such problems.

In the early 1980s, a survey carried out by the IAEA found that around 50 per cent of the equipment sent to its African Member States through projects was malfunctioning. Based on this feedback, the IAEA set up a six month practical, hands-on course specifically for scientists from countries that were introducing or upgrading nuclear equipment in their hospitals and analytical laboratories. The depth and breadth of this course and the effort taken to hold it annually within the NSAL is unique in the world. And its success can be measured. Thanks to regular feedback from participating countries, the IAEA estimates that the situation regarding the maintenance
Hands-on training supports success

Students who participate arrive with at least a basic knowledge of electronics and an understanding of maintenance principles, allowing them to move into areas of troubleshooting and repair. All staff members of the NSAL contribute to the training courses, not just lecturing but also providing the ten participants with hands-on opportunities for experiments and for undertaking actual repair work. Moreover, as every instrument is equipped with a computer or controller, the course has been adapted to include these technologies as well.

The IAEA constantly brings new techniques to the course to keep up with rapidly changing markets. For teaching, the NSAL uses its own gamma camera, a valuable instrument donated to the course by the manufacturer, who saw the advantage of having a large number of trained maintenance experts in the countries that own and operate the machines. The manufacturer also gives the IAEA access to its staff of experts and engineers to support the training courses.

In addition to the six months of training at the laboratory, the IAEA provides expert follow-up support and is ready to help the former students when they return to their countries, using modern communication technologies wherever possible. In the early days of the Internet, when connections were not very reliable and stable, IAEA experts even supported the repair of a gamma camera in an East African country via a leased satellite link. Although expensive, it still was just a fraction of what it would have cost to fly a repair team to the country.

Over the past 20 years, some 250 students from 50 countries have taken the intense six month course, while hundreds more have benefitted from short term workshops and training courses conducted in their countries. At one training course being held at an institute in Africa, the IAEA experts found out through a local newspaper article that the entire district would be disconnected from power for ten days for maintenance. In spite of phone calls explaining to the ministry that the workshop was under way, nothing could be done to postpone the power cut. But they found a solution: to carry out the planned experiments and exercises, they organized an old reliable workhorse — a diesel generator — which provided the power they needed to run the nuclear laboratory.
New portable spectrometer serves as mobile analytical laboratory

Although the underlying principles of X-ray fluorescence spectrometry are well understood, there is still considerable potential for new developments and applications. An X-ray fluorescence spectrometer (XRF) uses electromagnetic radiation to expose the elements contained in an object. This technique has been around since the 1950s, but the technology has continually evolved and increasingly serves the scientific community.

However, when the IAEA’s Nuclear Spectrometry and Applications Laboratory designed and constructed a portable version of a fluorescence spectrometer, its value became much more visible to the non-scientific community. The portability of the instrument enables it to serve as a mobile laboratory for testing for environmental pollution in the field by analysing soil and air contamination in situ. But, the portability has also given it an entirely new role — serving the world of fine arts. The portable machine can be taken to museums to provide information for comprehensive characterization of art treasures, such as helping to determine what kind of restoration work has been done in the past, revealing how it was done and providing information to assist conservation planning.

Measuring several elements simultaneously
Portable X-ray analysers have the capacity to detect and measure different elements simultaneously. Thus, they can be used in industrial areas to analyse particles that are in the air in order to identify sources of pollution,
or taken to fields contaminated with toxic elements, such as lead or arsenic, to identify and establish the distribution of the pollution. If the screening detects contamination hot spots, samples from those areas can be taken to the laboratory for more intense and accurate analysis. In addition to the advantage of its portability, the analysis it performs is completely non-destructive, which is especially important when analysing art objects.

Under a memorandum of understanding with the Kunsthistorisches Museum in Vienna, the IAEA participated in the development of a second version of the portable spectrometer. This version is now fully operational at the museum and is used for specialized measurements, such as identifying pigments in paintings, which assists conservators in selecting proper conservation strategies. When a handheld X ray fluorescence spectrometer was brought to the museum to characterize an extremely delicate sixteenth century Mexican headdress, the IAEA provided an interpretation of the measurements. While a previous radiographic inspection had revealed that some of the gold ornaments of the headdress had indeed been replaced, it was only when the handheld XRF was used that art restorers could see that the replacements were actually gold-gilded brass, most likely added during previous restoration processes.

While commercially available handheld systems are generally used to test for lead in paint or to screen scrap metal, the IAEA instrument was specifically designed to allow inspection of minute areas, on the order of some tens of micrometres. This feature is of special value for the inspection of works of art, where some small areas (such as welding elements used in metal artefacts) provide information revealing the techniques used by the original craftsmen when they created the object.
Spectrometer gives scientists a 3-D image of elemental content in environmental and archaeological samples

Although the land next to a factory has been tested and found to be contaminated, there is still a field of crops growing around it. However, these crops are not for harvesting and marketing. These crops are there to decontaminate the soil. Researchers have determined that certain ‘hyperaccumulating plants’ have the ability to absorb elements, bringing them out of the soil through their roots and into their stems and leaves. But the distribution of these elements is not homogenous within the plant structure; the concentration might be higher in the roots and lower in the stem and leaves, or vice versa. In order to better understand the plant’s uptake mechanism, the IAEA’s Nuclear Spectrometry and Applications Laboratory has developed a scanning micro X ray fluorescence spectrometer (XRF) with two microscopic X ray lenses capable of observing a volume with a dimension of less than 1/20 mm³. By moving the sample in front of the beam, the scientists can create 3-D images that visualize how the elements are distributed.

The same type of analysis can be used to identify the local distribution of radioactive elements in hot particles sampled from contaminated environments, such as the South Pacific atolls where nuclear tests were performed in the 1960s. In such cases, scientists use portable

A leaf from a mustard plant growing next to a factory, a chip of blue paint found in an archaeological dig, and a male and female tsetse fly engaged in a ritual mating dance — all potential samples to be studied by a customized spectrometer developed and constructed by the IAEA’s Nuclear Spectrometry and Applications Laboratory. This multipurpose instrument identifies elements present in the samples and then visualizes the findings in 2- and 3-D images. If the land next to the factory is polluted with metals, the mustard plant will absorb them through its roots and the spectrometer

will allow the scientists to see which metals were absorbed and where the plant stored them. Assessing the elements present in the chip of paint helps archaeologists to understand how ancient artists created their colours, such as the copper based blue pigment developed by ancient Egyptians and distributed throughout the ancient world. And being able to observe the nuances of the tsetse fly mating dance enables scientists working in pest control to test the impact of the procedures they use to prepare male insects for the sterile insect technique.
spectrometers to identify the hot areas and then take samples from precisely those areas back to the laboratory for a more detailed analysis. The more information gleaned about the elements that are in the environment and their relationship to each other, the more information researchers have for alleviating or taking measures against environmental contamination.

**Three functions — one instrument**

Archaeologists and conservation scientists who study ancient and historical materials have also benefited from the new analytical possibilities that this instrument offers. It enables a non-destructive analysis of the complex structures in materials, such as stratified paint layers, and then visualizes them in 3-D, increasing the understanding of what raw materials ancient civilizations used and what techniques they used to apply them. This information is helpful for developing and applying strategies for conservation of materials and artefacts that are part of the cultural heritage. For example, determining the type of natural mineral or synthetic colorant used in wall paintings tells archaeologists if it was a locally developed technology (e.g. the Egyptians themselves developed a copper based blue colorant) or if it arrived via ancient trade routes and exchanges among civilizations (e.g. mercury sulphide based cinnabar colorant was based on Asian or Balkan mineral deposits and then transferred to the Mediterranean basin).

One of the most exciting breakthroughs has been the ability to use the instrument to follow living specimens, such as the behaviour and dynamic morphology of mating insects. One of the world’s most successful methods for controlling insect pests on a large scale, the sterile insect technique (SIT), calls for sterilizing male insects and releasing them into the wild. When the sterile males mate with the fertile females, there are no progeny, thus creating a generational gap. The SIT has been used successfully for decades against fruit flies and other pests such as the tsetse fly. In addition to enabling the in vivo investigation of tsetse fly mating rituals, it has also provided an opportunity to study the morphology of tsetse fly reproductive organs and salivary glands, which provides beneficial information for entomologists involved in pest control.

In developing this instrument and its software, IAEA scientists have integrated the functions of at least three different commercial products into one. The software is provided at no cost to Member States. The IAEA has also developed a low cost, advanced and modern signal processing module for data acquisition and analysis, which has reduced the price by a factor of ten compared with corresponding commercial units.
Identifying banana varieties resistant to banana fungus through mutation induction

According to the annals of plant genetic diversity, the world is home to more than a thousand varieties of bananas. They come in colours ranging from red to black and from green to maroon, sweet ones ready to be eaten directly from the tree and starchy ones that need to be cooked. They also vary in nutritional value, including one Nigerian variety claimed as a cure of infertility. Yet shoppers are likely to find only one variety of banana for sale in their local supermarkets. In fact, that same variety will also be for sale at the market across town, in the next district, in the neighbouring country — yes, in just about all of the world’s supermarkets. The entire global commercial banana industry relies on one sweet, seedless banana variety, the Cavendish.

The Cavendish was adopted by the commercial industry because it had resistance to a disease that was threatening the banana world of the 1960s. Today, history repeats itself. Another banana disease, black Sigatoka, is circling the globe, and the Cavendish, which has no resistance, is in its path. The threat is especially dire because of the way these bananas are propagated; they are all essentially clones, which means that if one plant is at risk, all plants are at risk.

Fighting banana fungus as a race against time
But the banana industry is not really interested in adopting a new variety, because it would mean having to re-tool its entire processing infrastructure.
Thus, it is relying on a fungicide, sprayed on banana plantations from the air every six days – a fungicide that has been associated with stunted growth, miscarriages and other human health side effects. It also is expensive to use, putting it out of reach of many of the 400 million local people who rely on bananas to feed their families or for extra income.

Recognizing that the fungicide spraying will continue unless something is done to build black Sigatoka resistance into the current global variety, the FAO/IAEA Plant Breeding and Genetics Laboratory, a global pioneer and leader in the field of plant genetic mutation, has been in a race against time, working with countries to develop new varieties with the resistant traits. In the case of banana, the mutation process calls for irradiating thousands of banana plantlets with doses of gamma rays or X rays that cause random mutations. Then it is a matter of screening these plantlets to see if the mutations have affected the genes in a way that could lead to the sought-after trait — in this case, resistance to black Sigatoka. It is basically a numbers game: the better the screening technique, the greater the probability that the specific, one-of-a-kind improved banana will be detected.

To date, FAO/IAEA has developed three banana plant mutations that, under laboratory conditions, show a resistance to the black Sigatoka toxin that would normally kill the plants. The next step is to take the plantlets to the field, to see if the bananas they produce outside of the laboratory still have the necessary resistance.

The goal of FAO/IAEA’s work with plant mutations is to help small farmers and medium-size producers. Among others, it has produced commercial bananas that provide Sudanese farmers a 30 per cent higher yield and has introduced 600 Sri Lankan families to micro-propagation techniques that have increased family income 25-fold, resulting in the Government’s recommendation that local farmers consider switching from subsistence rice to value-added banana.
Improved barley varieties
FEEDING PEOPLE FROM THE EQUATOR TO THE ARCTIC

The weather conditions in the high Peruvian Andes, with their propensity for severe storms that bring with them high winds and hail, are not exactly hospitable for growing grains. But thanks to the work done by the FAO/IAEA’s Plant Breeding and Genetics Laboratory together with Peru’s national agricultural research system, barley varieties now exist that can be planted 3 000–5 000 metres up those mountains. These hearty grain improved varieties have become a lifeline for people who live at those altitudes, providing dependable as well as nutritious yields and now accounting for 90 per cent of the barley produced in Peru.

The work that supported this outcome began in the 1970s when the National Agrarian University—La Molina joined the FAO/IAEA in the use of mutation induction to breed the kinds of traits that would allow barley to survive in high altitude conditions. To date, the programme has developed nine varieties, such as La Molina 95, released in 1995, and Centenario II, released in 2006, which not only are grown at an altitude where no other modern crops can survive, but can also produce high yields, reaching 2.1 tonnes per hectare at 3 500 metres.

Mutant varieties expand barley’s realm
These mutant varieties thrive in the Andes because their ears nod below the crop canopy, which shelters them from the wind and hail, a small change with huge benefits. Another mutant allows barley to grow with less than the 16 hours a day of sunlight it normally needs to flower. Known as the ‘short-day mutant’, it enables barley to grow in equatorial countries such as Ecuador and the United Republic of Tanzania.
In these cases, as well as many others, mutation breeding has opened new environments for the crop to be grown.

Barley is grown for both food for people and feed for animals around the world. It naturally grows with awns, which are projections from the ear that carry barbs that most probably served to spread seeds by sticking to the fur of animals. However, these awns have no nutritional value, are sharp and cause painful cuts on the mouths of animals. Thus, another mutation has led to a variety that has rid the barley of its barbs without compromising yield.

As climates and consumer needs change, FAO/IAEA works with countries to ensure that their plant varieties match the reality of the situations in the fields and in the markets. It is a demand driven process, with countries making requests for new improved varieties that will meet their ongoing or changing needs. It is up to plant breeders to help farmers prepare for the future.

World population is increasing at the same time that there is a decrease in usable agricultural land, which makes it necessary to grow crops on less favourable or marginal lands and, at the same time, increase yields on good lands. As seen by the number of environments where new barley varieties are now growing and contributing to local food security, mutation breeding — with its ability to use local germplasm to develop new mutants to meet local needs — is a critical and efficient tool for responding to that challenge.
Salt tolerant rice varieties help Vietnam deal with changing climates

Once considered random and unscientific, mutation breeding has gained new respect in the scientific community as its work has moved from seemingly random successes to more targeted methods that have made the detection of mutations more efficient. This is in large part due to developments in mutation detection that enable the sampling of thousands of seedlings at a time.

In these times of changing global climates impacting traditional growing patterns, it becomes increasingly important to take advantage of the fast and effective opportunities plant mutation offers for developing new breeds to meet the new needs. In Vietnam, changing climates have increased flooding, which has led to inundation of salt along the coastal areas of the Mekong Delta, the primary rice growing area of the country. The FAO/IAEA’s Plant Breeding and Genetics Laboratory (PBGL) has worked with both government researchers and farmers in Vietnam in developing salt tolerant rice varieties to support Vietnamese farmers, including one known as VND 95-20. VND 95-20 is a mutant rice variety developed specifically to help the farmers of the Mekong Delta, known as the rice basket of Vietnam, cope with changing climates and soil conditions. It is especially important because of its ability to grow in the saline and acidic coastal soils, and now adds some US $300 million a year to farm income in the area. In addition, the fact that the FAO/IAEA has been able to find fast and effective solutions to help governments meet the changing needs of their farmers has led to a renaissance in the scientific appreciation for mutation breeding.

Over the decades, the FAO/IAEA’s Plant Breeding and Genetics Laboratory has worked with over 100 countries, developing and introducing mutant crop varieties that respond to ongoing or changing needs in the countries’ fields. A partnership between FAO/IAEA and the Government of Vietnam dating back to the 1970s has been extremely successful in breeding, selecting and testing new rice varieties to support Vietnamese farmers, including one known as VND 95-20. VND 95-20 is a mutant rice variety developed specifically to help the farmers of the Mekong Delta, known as the rice basket of Vietnam, cope with changing climates and soil conditions. It is especially important because of its ability to grow in the saline and acidic coastal soils, and now adds some US $300 million a year to farm income in the area. In addition, the fact that the FAO/IAEA has been able to find fast and effective solutions to help governments meet the changing needs of their farmers has led to a renaissance in the scientific appreciation for mutation breeding.

Improving crops through enhanced biodiversity

The treatment included irradiating seeds of traditional Vietnamese rice varieties with gamma rays which, in effect, created additional genetic variability in those seeds. While some traits, such as colour and shape, are obvious, other traits such as disease resistance or tolerance to various climates and soil conditions are not visible, and methods of detection are needed. Thus, FAO/IAEA developed a rapid seedling test to screen thousands of seedlings for their saline tolerance using hydroponics —
mineral nutrient solutions in water without soil. The vast majority of the seedlings died, but one or two mutants survived and produced seeds, which were then returned to Vietnam for field testing in the actual saline fields where they were bred.

If left to nature, this process of mutation would evolve slowly over millions of years. With the gamma rays, it is sped up to a matter of just a few minutes. In seeking traits such as salt tolerance, the researchers will grow the seeds in tanks filled with liquid of varying degrees of salinity. As the plants grow they are scanned for how they perform, thrive or suffer. FAO/IAEA has developed and shares low cost protocols that countries can use for screening, such as the hydroponics seedling test for salt tolerance.

Advances in science that now enable scientists to look at the genomes of plants have truly changed the attitude toward genetic mutation. Geneticists first worked with only simple organisms and then moved to more complicated ones, starting with bacteria, then yeast and then mice. The first organism mutated was Arabidopsis, a weed in the mustard family. Now, scientists have genomic tools to work with all crops. It is not just a matter of choosing mutations, it is now possible to determine how the gene works and to detect important gene mutants that have the DNA code for desired traits.

The proof of the success is now in those fields. Nine mutant varieties that had their beginnings in the FAO/IAEA’s PBGL and have been accepted for planting in Vietnam are now registered as national varieties and are grown on 500,000 hectares. The Mekong Delta now supplies more than half the rice grown for national consumption and 90 per cent of the rice grown for export. VND 95-20 alone is now responsible for more than US $300 million a year to the farmers of the region.
Farmers around the world benefit from crop varieties developed through induced mutation

The concept of mutant breeding was first described in the 1920s, when researchers discovered they could greatly increase the number of mutations by exposing plants to X rays. The first induced mutant crop was a tobacco variety produced in Indonesia in 1934. The process of mutation induction accelerated greatly after World War II, when the techniques of the nuclear age became available and seeds could be exposed to gamma rays and other radiation sources. The FAO/IAEA's Plant Breeding and Genetics Laboratory has consistently supported improvements in the technology. It now harnesses the knowledge of genomes to identify DNA markers, which speeds up the process and makes it more efficient.

The process itself is also cost efficient. Thousands of plant seeds or tissues are irradiated briefly, usually for only a few minutes, which causes mutations in the DNA. Irradiation by X ray or gamma ray is a process that produces no residual radiation or toxic effects. The seeds are safe for immediate use. The scientists then select those plants with the desired mutation. Sometimes the mutations are visible, such as those affecting height, colour, shape or other physical characteristics. But others, such as disease or drought resistance, require further detection. Mutation detection can be sped up because it is possible for the scientists to look at the mutations on the actual genes that determine disease or drought resistance.
Impact of mutation induction in farmers’ fields

Over the decades, FAO/IAEA has worked with over 100 developing countries in meeting demands for crop improvement by inducing, detecting and developing mutants to produce new, superior varieties. The traits they look for can range from those that enable the plant to withstand extreme or changing climatic conditions or resist emerging pests and diseases to those that have better nutritional values or simply taste or look better and meet consumer demands.

Promotion of mutation induction by FAO/IAEA has helped increase global acceptance of induced mutations in plant breeding without restrictions, and their impact is seen in farmers’ fields around the world. To date, more than 3 200 mutant crop varieties have been registered in FAO/IAEA’s Mutant Variety Database, varieties responsible for contributing billions of dollars annually to the economies of developed and developing countries.

New varieties have been created specifically to meet the needs of farmers, such as a new variety of the ancient grain kiwicha that has higher yield and better quality and appearance and is now grown as an export crop in Peru; a high yielding, disease and insect resistant sesame variety in Egypt; disease resistant cocoa in Ghana; and drought tolerant wheat in Kenya. In each case, FAO/IAEA’s participation in this work was strictly demand driven — it responded to its Member States’ needs.

FAO/IAEA is also deeply involved in global efforts to thwart the impact of UG99, a virulent wheat rust currently circling the globe that threatens wheat crops. With its global membership, FAO/IAEA is in a position to work with its members and encourage their sharing of germplasm. In the past, nations kept two-month stocks of wheat in reserve, which were constantly replenished. Today, because of the UG99 concern, those that can afford it are shifting to four-month stockpiles, which is taking wheat off the market and, in turn, leading to higher prices. A disease such as UG99 highlights the precariousness of the global food supply. It also highlights the critical contribution genetic mutation can make, not just to improving harvests of individual countries but also to global food security.
Each year in Bangladesh, about 2.8 million ha of coastal lands suffer from salinization, as seasonal high tides bring seawater some 15–30 kilometres inland. Until recently, this meant that the area’s farmers could only plant rice during the monsoon, when rains diluted the salt build-up. The rest of the year, the land had to remain fallow. Today, thanks to research undertaken in the FAO/IAEA Soil and Water Management and Crop Nutrition Laboratory and in the coastal areas of Bangladesh, scientists have introduced water management practices that use seawater mixed with rainwater harvested during the rainy season to irrigate salt tolerant crops in the dry season. This ensures that sufficient water is available for crop growth without increasing soil salinity. FAO/IAEA has also evaluated and identified salt tolerant rice and legume crops, such as groundnut, mung bean and chickpea varieties that not only grow but thrive in salty soil. Crop production on these seasonally salt affected soils has the potential to add more than US $4 billion to the national economy each year.

Carbon isotope techniques identify salt tolerance
Carbon isotope discrimination (CID) measures the extent to which plants discriminate against the heavier carbon isotope $^{13}$C in favour of the lighter $^{12}$C isotope during photosynthesis. CID was originally developed to evaluate drought tolerance in crops, but FAO/IAEA adapted the methodology to
test the ability of a plant to use water efficiently in salty soils. Using CID to evaluate the plant’s leaves or grains under different soil salinity levels at different crop growth stages, the FAO/IAEA and Bangladeshi scientists identified local salt tolerant varieties of rice and legume crops that can be planted during the dry season.

FAO/IAEA works with researchers in Bangladesh, conducting field trials and evaluating the performance of these improved crop varieties under existing soil and climate conditions. This includes evaluating grain yield and salinity tolerance under different water management practices and their adaptability to local soil and climate conditions in different agro-ecosystems. For example, field testing determined that the salt tolerant rice variety Binadhan 8 can be grown in soils with a salinity of up to 4.5 g of salt per kilogram and still yield 6–7 tonnes per hectare.

FAO/IAEA now estimates that adopting salt tolerant rice varieties plus water management practices that use seawater mixed with rainwater will enable a second rice or legume crop to grow on much of the 2.8 million ha of coastal lands that are unusable during the dry season, benefiting around 1 million resource-poor farmers. Not only will this mean additional income and nutritional diversity (with legumes as a source of protein), but it will also leave the soil in a better condition.

With field testing completed, efforts are now focused on recommending the new salt tolerant crop varieties and water management practices to farmers through up-scaling to different agro-ecosystems. The goal is to introduce the salt tolerant varieties of rice and legume crops on at least 1 million ha by 2015, which will increase the rice production in Bangladesh by another 15 per cent, raise self-sufficiency to 85 per cent and potentially add about US $4 billion to the national economy from rice alone.

Although this work began with a focus on the situation in Bangladesh, the technology is now being shared with other countries that have salinity issues, including Algeria, Eritrea, Indonesia, Iraq, Mauritius, Morocco, Oman, Pakistan, Qatar, Senegal and Yemen. FAO/IAEA has trained researchers from these countries and has initiated projects to improve crop production by taking the new techniques to their fields.
Biological nitrogen fixation

A NATURAL AND NO COST BIO-FERTILIZER

In sub-Saharan Africa, if nitrogen fertilizer is available at all, it is expensive, often costing eight times more than it would cost in Europe, putting it out of reach for most of the region’s small-scale farmers. However, judicious planting of legume crops has the potential to replenish the nitrogen in the soil through a natural process known as biological nitrogen fixation, while also providing farmers an extra crop that they can use to feed their families or can sell for additional income. Since the 1970s, the FAO/IAEA Soil and Water Management and Crop Nutrition Laboratory has promoted the introduction of legumes into crop rotations as a profitable and environmentally friendly way to improve the production, income and food security of smallholder farmers, such as those in the arid and semi-arid regions of sub-Saharan Africa.

Plants use the nitrogen that is biologically fixed for growth of leaves, stems and roots, and for production of grain. After the grain harvest, parts of the plant are left behind in the field as residue. As the residue decomposes, the nitrogen becomes incorporated into the soil as a natural fertilizer. This replenishes the soil nitrogen which, in turn, will nourish the next crop that is planted in the field.

Technique improves soil quality and yield

In order to quantify the nitrogen-fixing contribution of individual legumes, FAO/IAEA developed a technique that calls for planting a legume and a cereal next to each other in a field where fertilizer enriched with $^{15}$N has been added. This $^{15}$N isotope is heavier than the normal $^{14}$N isotope and thus can be traced by measuring the $^{15}$N and $^{14}$N concentrations in the plants. The cereal serves as the reference plant, because it can only absorb nitrogen from the fertilizer or from the soil itself, while the legume
can also absorb nitrogen from the air. The level of nitrogen fixation can be estimated based on the difference between the two isotope concentrations. FAO/IAEA has carried out both national and regional field projects and coordinated research projects to test grain and forage legumes in more than 40 countries to identify the most suitable legumes for different regions and agro-ecosystems of the world, and then disseminated the technology through fellowship training and workshops.

Different parts of the world have different uses for legume crops. Each year, Brazil produces around 72 million tonnes of soybean, a grain legume that is sold in local and overseas markets. Using the $^{15}$N methodology, FAO/IAEA showed that, due to biological nitrogen fixation, Brazilian soybean production is almost self-sufficient in nitrogen, meaning that the soybeans are produced with little or no application of nitrogen fertilizer. The value of the biologically fixed nitrogen in Brazil’s annual harvest is estimated at more than US $1 billion in terms of urea fertilizer equivalents.

The situation is somewhat different in sub-Saharan Africa, where small farmers are more interested in producing crops to feed their families than for markets. For them, it is important to use dual purpose crops such as cowpea, pigeon pea and groundnut that improve soil fertility but also provide food security for the family. For example, cowpea, pigeon pea and groundnut are grown on more than 16 million hectares in sub-Saharan Africa, producing about 16 million tonnes of grain legumes. While the $^{15}$N technique found that these dual purpose food legumes are not as efficient at biological nitrogen fixation as the Brazilian soybean, they still return approximately 750 000 tonnes of fixed nitrogen to the soil.

Looking at the global picture, each year major grain legumes biologically fix an estimated 11.1 million tonnes of nitrogen. This indicates that the inclusion of legumes in cropping systems could result in nitrogen deposits worth approximately US $13.5 billion, equal to more than 30 per cent of the annual nitrogen fertilizer requirement of all developing countries.
Isotopic method measures soil evaporation and improves water use efficiency and crop productivity

Water resources are becoming increasingly scarce in many parts of the world at the same time that intensification of crop production systems is increasing water demand and putting further pressure on the resource. In Vietnam, coffee farmers depend on rainwater for coffee bean production, but because of increasing water scarcity, coffee yields have declined, affecting farmers’ livelihoods. Farmers in the North China Plain, where fresh water is becoming increasingly scarce, use 70 per cent of their water to produce maize and wheat, but their water use efficiency is low. However, by incorporating improved management practices, some 30 per cent of the irrigation water used can be saved without affecting yield.

While both the Vietnamese and Chinese farmers were well aware that they were losing a significant amount of water through evaporation, the extent of that loss was not easy to determine due to the dynamic nature of the processes involved. The FAO/IAEA Soil and Water Management and Crop Nutrition Laboratory adapted a method to measure the isotopic compositions of water vapour surrounding the crop (the oxygen and hydrogen isotopes $^{18}$O and $^2$H) and simplified a method to extract the water from soil and plant samples for determining its isotopic composition. Until recently, extracting water from these samples presented a roadblock, as existing methods were often cumbersome and labour intensive. The new method developed by FAO/IAEA scientists is fast, accurate, inexpensive and portable.

Improved information improves water management

The isotopic composition of water that has evaporated from soil differs from that of water that has transpired from plants. This enables scientists to break down water lost through evapotranspiration into its individual
components of soil evaporation and plant transpiration, thus providing information on the effective water requirement of crops. On-farm management practices can then be put into place to reduce soil evaporation through mulching and soil conservation tillage, or to improve irrigation schedules in order to ensure that crops receive water when they most need it.

For example, studies in coffee fields in Vietnam found that almost half the soil evaporation happened during the maturation and canopy-forming stages, and was lowest during the bud development and flowering stages. It also so happens that coffee plants need the most water during the dry season. Using this information as a base, scientists in Vietnam used simple management strategies to retain soil moisture. For instance, simply covering the soil surface under the coffee plants with a 5–10 cm layer of old branches and leaves reduced evaporation from 17 per cent to a mere 5 per cent, while enhancing the sprouting of new buds and stabilizing the soil structure.

Using similar tests on winter wheat in China, Chinese scientists found that the highest evaporation loss occurred during the sowing and the pre-flowering periods. Together, FAO/IAEA and the Chinese Academy of Agricultural Sciences (CAAS) and the China Agricultural University (CAU) developed irrigation plans that incorporated the specific needs of the crop and managed to save 33 per cent of the irrigated water while maintaining grain yield above 7 tonnes per hectare.

China and Vietnam are part of a network involving eight countries that use this isotopic approach to separate soil evaporation and plant transpiration for a range of crops growing under different land use and agro-ecological conditions. Guidelines from the findings are being developed to support farmers not only in Vietnam and China, but also in Pakistan, Turkey and other parts of the world.
Soil conservation
PROTECTING SOIL RESOURCES

Soil degradation through erosion is a fact of life on Earth. Worldwide, soil degradation is currently estimated to affect 1.9 billion hectares (ha), and it is increasing at a rate of 5–7 million ha each year. An estimated 1.5 billion people, a quarter of the world's population, depend directly on the productivity of these degraded lands. This situation, where food production is impeded, is further complicated if the eroded soil moves down hillsides into waterways, carrying with it fertilizers, pesticides and other agrochemicals that can diminish water quality.

A major first step in efforts to stem the flow of soil from agricultural fields requires determining where and how much erosion is actually taking place. The FAO/IAEA Soil and Water Management and Crop Nutrition Laboratory supports projects in erosion prone areas around the world — including hillsides in Chile, Tajikistan and Vietnam — that measure soil erosion using nuclear techniques. These measurements provide agricultural scientists with the kind of information they need to judge how much current farming practices prevent or promote soil erosion and whether they are good or bad for the local environment.

The method used to measure soil erosion makes use of the fact that nuclear tests conducted in the 1950s and 1960s released radioactive particles of $^{137}\text{Cs}$ into the atmosphere, so called radionuclides, that had not been there before. Other radionuclides that are used in assessing soil erosion rates are naturally occurring radioactive materials present in the atmosphere (such as $^7\text{Be}$ and $^{210}\text{Pb}$). Through rainfall, these radionuclides are deposited on the soil surface and absorbed into the soil. They subsequently move when the soil moves, and thus can be used as natural tracers, giving a picture of the extent of soil erosion.
Measuring soil loss in order to control or mitigate erosion

Measuring the movement of radionuclides on a hillside first requires identifying a reference area — a flat piece of terrain, such as a grassland area, that would have had no new deposits of soil from eroded areas. The radionuclide count in the reference area is then compared with the count in the eroded areas at the top of the hillside and that in the deposit area at the bottom. Once the radionuclides are counted, mathematical models are used to determine how much soil is lost a year.

Using this radionuclide approach, in 2008, Chilean scientists not only measured erosion losses in the vineyards at up to 82 tonnes per hectare per year, but they also determined that soil eroding from their hillsides was adding sediment to downstream water reservoirs. Terracing vineyards was found to reduce the erosion by a mere 7 per cent, while planting permanent ground cover between the vines reduced it by 50 per cent. With this knowledge, the practice is now being implemented in vineyards covering some 3200 hectares in Chile.

As a complement to the fallout radionuclide based method that measures how much erosion there has been, FAO/IAEA has also introduced compound specific stable isotope (CSSI) analysis. CSSI analysis can identify the source of eroded soils through the soil’s isotopic signatures, which enables scientists to pinpoint where the erosion has taken place, including where the sediments at the bottom of the hill actually originated. This technique has proved useful in linking upland and lowland agricultural practices in Vietnam, enabling farmers to reduce upland soil erosion and at the same time improve lowland rice productivity through improved water and nutrient availability.

In Tajikistan, farmers have taken remedial action to combat soil erosion that includes placing irrigation furrows along the contour lines of slopes. This has effectively controlled soil erosion and reduced soil fertility losses in hill slopes of less than 8 degrees in the Pamir Mountains.

FAO/IAEA has implemented similar projects in over 40 countries, including Argentina, Brazil, China, Madagascar, Mongolia, Morocco, Tunisia and Yemen, providing farmers with science based information that tells them, first of all, the extent and sources of soil losses from agricultural landscapes, and that also provides them with practical information that will help them control or mitigate those losses.
Reference materials

LABORATORY CALIBRATION IMPROVES PROTECTION OF CONSUMERS AND ENVIRONMENT

Just as the prototype kilogram — against which all other kilogram weights are measured — resides in the International Bureau of Weights and Measures outside of Paris, the prototype sample of water resides in the IAEA's Terrestrial Environment Laboratory (TEL) outside of Vienna. This sample is known as Vienna Standard Mean Ocean Water 2 (VSMOW2), although in actuality it contains neither salt nor other substances usually found in seawater. Instead, VSMOW2 refers to pure water with a particular mix of isotopes that world experts have agreed represent the average of all the world’s oceans.

The first batch of VSMOW, ‘distilled’ in the 1960s, was distributed to laboratories by the IAEA in the form of 20 mL samples for the next 40 years. Laboratories used the samples to ascertain calibrations of their instruments and thus improve the accuracy of their water assays and measurements. In the early 2000s, the original supply began to run out. This meant that the IAEA had to undertake the task of recreating the sample: it took five laboratories four years and hundreds of independent measurements to produce and verify VSMOW2, a new sample that came close enough to replicating the original VSMOW. Once there was agreement on the new sample, the IAEA produced 300 litres in 2006, which is expected to last another 50 years.

VSMOW2 is just one of some 100 materials from land, sea and air — ranging from samples of soil, vegetation, crops, gasses and fish flesh — that are produced and distributed by TEL and that serve as global reference points for measurements of radionuclides, stable isotopes and trace elements. This work of the IAEA contributes to aligning the scientific community, making
sure that laboratories everywhere are testing to the same standards. If this is assured, the data that the laboratories produce can be used with confidence by those involved in trade, environmental protection and consumer safety.

Governments want proof that imports meet their national quality control standards in areas such as levels of pesticide residues in crops or of radionuclides in fish. Lack of proof that products have been tested in certified laboratories can be a barrier to international trade. A trader buying the catch of a fishing trawler who wants assurance that the fish was not taken from polluted waters can rely on a laboratory that has checked its instruments to the IAEA standard of fish flesh.

**Creating a reference sample**

The IAEA works with advisory groups from around the world, discussing scientific topics and trends, and determining if a new reference product is needed or if an existing one needs to be renewed. If a new reference material is requested (e.g. for radionuclide levels in milk powder), up to ten different laboratories may be involved in the process of developing it, a process that will take at least one year, but on average three years.

Once the reference material is produced, laboratories are limited in how often they can receive samples. When the original batch is depleted, a new one will be produced, coming as close as possible, but never being exactly identical, to the original.

Over the years, the IAEA has distributed thousands of samples of its various reference materials to laboratories around the world. In 2011, it saw a 30 per cent increase in demand, in part related to the accident at the Fukushima Daiichi nuclear power plant, but also because, as trade increases in a globalizing world, consumers increasingly 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 has expanded its storage and dispatch facilities and has established an interactive web portal both for acquiring reference material orders and for reporting analytical results of laboratory tests.

**REFERENCE MATERIALS SALES FROM 1999 TO 2011**

![Graph showing reference materials sales from 1999 to 2011](image)

**LEFT:** Reference materials shipment office.

**CENTER:** Vienna Standard Mean Ocean Water 2 (VSMOW2) and other reference water samples for calibration of stable isotope ratio mass spectrometers.

**RIGHT:** IAEA reference materials of various matrices, certified for different types of analytes (radionuclides, trace elements, organic contaminants).
In 2005, the participating nuclear analytical laboratories tested radioactivity in soil samples; in 2007, they measured artificial and natural radionuclides in water, soil and spinach; and in 2009, gamma emitting radionuclides in simulated air filters were analysed. Other years, the laboratories have analysed samples of phosphogypsum and of grass. This is all part of the efforts of the IAEA’s Terrestrial Environment Laboratory to promote analytical quality assurance and quality control through testing the proficiency of laboratories that use nuclear techniques to carry out measurements and analyses. These annual proficiency tests, which began in 1996, challenge the laboratories to be creative in problem solving as well as accurate.

In parallel with its proficiency testing, in 1995, the IAEA established the worldwide network of Analytical Laboratories for the Measurement of Environmental Radioactivity (ALMERA). Governments nominate laboratories to be members of ALMERA, selecting those that would be expected to provide reliable and timely analysis of environmental samples in the event of a release of radioactivity — either accidental or intentional. As of 2012, ALMERA had 128 members, representing 81 countries, which participate in the IAEA’s proficiency testing. In addition to improving their ability to meet their own country’s needs, the laboratories conduct inter-laboratory comparison exercises, which prepare them to work together in the case of an event of international significance.

The proficiency tests, by far the most involved of these quality control activities, are offered on a worldwide, regional and even national basis, if
needed, and they are not just offered to ALMERA member laboratories. In 2009, 1,800 samples were prepared and distributed to 300 laboratories in 76 countries worldwide, while a separate Latin American regional proficiency test called for Latin American laboratories to determine the trace elements and radionuclides in algae, soil, and spiked water. In 2011, 300 participating laboratories worldwide were asked to measure the presence of radionuclides in three water samples and one soil sample. Also in 2011, in response to the nuclear accident at the Fukushima Daiichi nuclear power plant, the IAEA developed a proficiency test specifically for Japanese laboratories, tasking them with determining radionuclides in soil, grass, water, and air filters.

**Laboratories taking tests**

For the test itself, laboratories register on-line, providing details of what kinds of instrument they use that can detect radioactivity in the environment, such as gamma ray, alpha or beta spectrometry. They then receive a package containing instructions and the actual materials to be tested. The tests are designed to challenge the laboratories and to force them to think creatively about how to solve the problems presented. Of course, the IAEA knows the target value before it sends out the material, so when the laboratories send back their results, the IAEA checks them against what it knows to be correct.

A comparison of the performance of the ALMERA laboratories against the performance of all 300 laboratories worldwide shows a gap in results. For example, 80 per cent of the ALMERA laboratories had acceptable performance, 9 per cent received a warning that their results were not close enough to the standard answer, while 11 per cent of ALMERA laboratories had unacceptable results. The worldwide performance found 69 per cent to have acceptable results, 8 per cent received a warning, and 23 per cent produced results that were not acceptable.

Looking over the years since the testing began and ALMERA was formed, the IAEA has seen continuous improvement in the results of all laboratories. Both the testing and the network have raised the awareness in developing countries, which often have limited human and technical resources, of the importance of investing in developing their capacities. As a result, many countries have increased the number of analytical techniques they are capable of using. This not only improves critical expertise, but also contributes to a country’s preparedness and response capabilities in the case of a nuclear emergency.
Environmental impact assessment
PROVIDING BASELINE ENVIRONMENTAL DATA

For centuries, the ill and infirm sought healing hot spring waters in health spas around the world, long before anyone understood that the magical healing powers often came from a high level of radioactivity in the water, in the form of radon gas. Today, visitors to those spas usually are only allowed to remain in the water for limited periods of time, because scientists now know that problems could arise from overexposure to the radon gas. The same applies to guides who take visitors on tours of underground caves in Hungary. Their work hours are controlled because the levels of radon gas naturally present in those caves can be harmful with too much exposure.

Radioactive particles — radionuclides — exist naturally in air, water and soil, not to mention in the muscles, bones and tissues of every human on Earth. Radionuclides emerge from the soil, beam down as cosmic rays from the sun, or are released during X ray and other tests for diagnosing disease, during radiation treatment for cancer therapy and as part of industrial and mining activities. At the extreme end, they enter the environment through nuclear material used in conventional ammunition or potentially through dirty bombs released as terrorist acts. Regardless of the source, intent and usage, at certain levels all radionuclides can be harmful.

This makes it critical to understand the movement of radionuclides in the environment, to know what levels occur naturally and what is occurring because of human actions, and how to minimize any detrimental effects. This requires that baseline studies be conducted before a nuclear power plant is built or mining or industrial activities are established, and that site specific prediction models be developed so that any changes can be identified quickly, when the industries are up and running or after a nuclear event, whether natural or caused by humans.
The baseline data can also support clean-up efforts, because when trying to reclaim contaminated land, it is important to know the baseline in order to determine if the land has returned to its natural state. For example, during the Soviet era, 18,000 km² of land in Kazakhstan was contaminated by hundreds of nuclear tests conducted above and below ground from 1949 until 1989. Today, thanks to a review of the area with the Kazakhstan Atomic Energy Agency, the IAEA’s Terrestrial Environment Laboratory has determined that some 3000 km² are again suitable for livestock breeding and housing, and it is expected that up to 95 per cent of the land will be reclaimed for agriculture in the next ten years.

Establishing baselines that enable measurement of the impact of radioactive contamination on the environment and humans is a complicated process that evolves over a series of stages. It must take into consideration the type of soil the radioactive particles go into, what organic matter is involved and whether the particles can be transferred to plants and through those plants into animals, thus becoming food for humans. This estimation is based on mathematical models that can predict the outcomes at each of these stages.

Proper monitoring and management of the environment requires local and regional assessments and the establishment of remedial strategies that are cost effective and socially acceptable. The IAEA works with its Member States to increase understanding of environmental processes, providing training and building national capacity to design and implement environmental monitoring programmes and remediation strategies based on a realistic picture of the national environmental situation.

The 600 page IAEA publication Quantification of Radionuclide Transfer in Terrestrial and Freshwater Environments for Radiological Assessments was compiled over the course of six years specifically to provide reference values for the most commonly used transfer parameters in radiological assessment models. It is a companion to the IAEA Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments (Technical Reports Series No. 472). These two publications serve as key references for radio-ecologists, modellers and government authorities, providing the critical baseline data needed for use in environmental impact assessments.
Any environmental survey, impact assessment or monitoring activity starts with taking samples from the area to be surveyed, assessed or monitored. But taking an environmental sample involves a lot more than scooping up bits of soil with a shovel and transporting them to a laboratory for testing. It is first necessary to determine exactly where to take those samples, how deep to dig, how big a surface area to sample and how much soil to take, even how to maintain the integrity of the samples while transporting them to the laboratory. Sampling techniques also change according to how the land is used — that is, whether it is an agricultural, semi-urban or urban area.

In 2005, the IAEA’s Terrestrial Environment Laboratory organized a soil sampling exercise in a field set up as test site in Italy. The participants — ten teams from laboratories that are members of the Analytical Laboratories for the Measurement of Environmental Radioactivity (ALMERA), a global network of laboratories founded by the IAEA — were asked to determine where and how to remove samples from a one hectare agricultural field before sending them to a laboratory for testing.

The fields had already been characterized in depth by Italy’s Higher Institute for Environmental Protection and Research (ISPRA). The goal of the exercise was not to determine the quality of the field environment, but rather to raise awareness of how greatly results can vary according to the sampling strategy used.

Teams sample same site, with different results
At the test site in Italy, teams were asked to collect samples using their own strategy and procedures, including sampling strategy and pattern, type of sampling design, sampling device and sampling depth. Test rules gave the
teams time limits and limited the sample volume. The collected samples were analysed, and the evaluated results indicated just how critical the samples themselves are to the outcome of the test.

When it was over, the IAEA compared the results of the different approaches used by the teams and determined that the most suitable, dependable method was a random stratified sampling strategy. At the same time, they learned that on-site sieving or any other processes that could cause segregation of the sample itself should be avoided.

The IAEA has published these results, sharing them with laboratories around the world. The test has raised awareness of the importance of determining proper strategies for field sampling and of increasing rapid response capabilities in the event that there is a need to sample an area possibly contaminated by the release of radioactivity in the environment.