Nuclear techniques for food and agricultural development: 1964-94

A look at selected achievements of the Joint FAO/IAEA Division as it marks its 30th year of worldwide service this October

by Björn Sigurbjörnsson and Peter Vose

From research laboratories to farmers' fields, nuclear techniques play an increasingly valuable and often unique role in agricultural research and development. They are used in a wide range of applications, from food preservation to crop production to animal health studies.

In no small measure, the collaborative work of two global organizations — the IAEA and the Food and Agriculture Organization (FAO) of the United Nations — has been instrumental to the progress. Thirty years ago, in October 1964, the two agencies combined forces to form a Joint Division for Nuclear Techniques in Food and Agriculture. The new division unified FAO's atomic energy branch and IAEA's agricultural unit, and in the process created a common programme that avoided overlap and duplication of efforts.

Over the past 30 years, programmes of the Joint FAO/IAEA Division have helped countries solve practical, and costly, problems in areas of soil fertility, irrigation, and crop production; plant breeding and genetics; animal production and health; insect and pest control; agrochemicals and residues; and food preservation. The Division's overall objectives are to exploit the potential for application of isotopes and radiation techniques in agricultural research and development; to increase and stabilize agricultural production; to reduce production costs; to improve the quality of food; to protect agricultural products from spoilage and losses; and to minimize pollution of food and the agricultural environment. On the occasion of the Joint Division's 30th anniversary year, this article highlights selected achievements over the past three decades.*

Mr. Sigurbjörnsson is Director of the Joint FAO/IAEA Division and Mr. Vose is a former senior staff member of the Division. Both were among the founders of the Division in 1964.

Soil fertility and nitrogen fixation

Agricultural researchers have long suspected that a great deal of fertilizer is wasted by being wrongly applied and consequently never gets taken up by the crop. The problem drew the attention of experts of the Joint Division in the 1960s, but they realized that possible solutions could be expensive. The Division's first co-ordinated research programmes on rice and maize, however, demonstrated that the use of the isotopes phosphorus-32 and nitrogen-15 in worldwide field studies was economically feasible. The finding stimulated the widespread use of nitrogen-15 in agricultural research, and had a major influence on extending the use of isotope techniques to many developing countries.

In subsequent years, FAO/IAEA-sponsored experiments on rice fertilization in the Far East, Hungary, and Egypt helped solve critical problems concerning the proper placement of phosphorus and nitrogen fertilizers. It was found that phosphorus should be given on the surface, whereas that would be the worst possible circumstance for nitrogen, whose surface applications would not be taken up by the crop. While this had been suspected from years of traditional experimentation, it had not been proven before.

A co-ordinated programme with maize further showed that the uptake of phosphorus was increased when it was mixed with nitrogen fertilizer, and that application of some nitrogen at the time of tasselling resulted in very effective uptake and increased crop yield. Recommendations based on these experimental results have been adopted by the FAO fertilizer programme, as well as by many countries, thus helping to save millions of dollars in fertilizer costs.

*A more comprehensive report on the Joint FAO/IAEA Division and its work appears in the 1994 edition of the *IAEA Yearbook*

Similarly, for tree crops, the Joint Division's work showed that effective placement of fertilizer can offer savings over many years. While traditional fertilizer experiments with tree crops take years to perform and evaluate, the use of fertilizers labelled with isotopes can help researchers determine root activity. The Division's programme showed that traditional placement of fertilizers was not optimal in many cases.

More recently, research has been intensive on the subject of biological nitrogen fixation from the atmosphere. The work has been prompted by the high costs and often poor availability of nitrogen fertilizers in developing countries, plus the need to reduce fertilizer levels in developed countries. It is quite difficult to measure the amount of nitrogen fixed by a crop, but the Joint FAO/IAEA Division has been among the pioneers in the development of methods using nitrogen-15. These methods give good results and have been used in major co-ordinated research programmes determining the nitrogen fixing capacity of beans and other legumes, of pastures, of nitrogen-fixing leguminous trees, and of *Azolla*, the pond weed that supplies nitrogen to rice paddies.

Soil moisture and irrigation

The efficient use of water in irrigation systems requires continuous monitoring of the level of soil moisture and interpretation of these measurements. The use of nuclear techniques to measure soil moisture has enabled soil physicists to redesign irrigation regimes and better plan the use of scarce irrigation water. At the same time, the productive potential of the land can be maintained or improved.

FAO/IAEA co-ordinated research programmes have shown that traditional irrigation methods can be improved to save as much as 40% of total water use; the saved water can be used to irrigate other areas. Researchers in a number of countries have tested different practices to increase water conservation in rainfed areas, with results leading to immediate practical applications.

Mutation plant breeding

In 1964, mutation breeding was frequently derided. Long-established plant breeders had difficulty in believing that inducing mutants through radiation in an apparently random manner had any relevance to their classical procedures, with careful crossing of different parent plants and selection and re-selection of their progeny. But attitudes have greatly changed, in great part due to the Joint Division's programmes. In reality, mutation breeding has been one of the big success stories —1800 improved mutant cultivars released to date— with an impact so great that we don't attempt to assess its monetary value.

A turning point was probably an international conference sponsored by the FAO and IAEA in Rome in the Spring of 1964. At that time, the number of known released mutant cultivars was less than fifty. At the conference, it was agreed that co-operative work was needed to solve problems in effective mutation treatment conditions, and in the subsequent screening, selection, and application of mutants, among other areas.

There was a serious lack of knowledge about how to start a mutation breeding programme and how to incorporate a useful trait into the best existing varieties. This challenge was taken up by the new Division. The FAO/IAEA *Manual on Mutation Breeding* was the answer. This publication has had enormous influence, becoming a standard text for plant breeders. On the practical side, a very significant development was the design of a facility (SNIF—Standard Neutron Irradiation Facility) to provide plant breeders with a pure source of fast neutrons in pool-type reactors.

An early FAO/IAEA programme was concerned with testing mutant durum wheat cultivars in the Mediterranean and Near East. Mutant cultivars of durum wheat are now among some of the most successful grown, with almost 70% of the total acreage of durum in Italy under mutant varieties.

Pioneer mutation breeding also was done on barley, leading to a situation today where virtually all barley cultivars grown in northern and central Europe have induced mutations in their parentage, coming about through a "cascade" process of newer varieties.

Mutation breeding in rice has been extremely successful. Largely as a result of the 1964 conference, a major co-ordinated rice improvement programme using mutation techniques was developed under FAO/IAEA auspices. The result was a high number of improved new varieties bred with the help of induced mutations. Before the programme began, there were four released mutant cultivars of rice. Today there are more than 200. Worldwide, there are many millions of hectares under mutant rice cultivars and the impact has been enormous.

The Joint Division has addressed other problems as well, such as crop resistance to diseases and the protein content of cereal grains. From studies of the annual cereals like barley, wheat, and rice, research moved to grain legumes, fruits, and root and tuber crops. The programmes on grain legume improvement resulted in more than 100 improved cultivars.

Vegetatively propagated crops presented much greater problems — except for the multimillion dollar house plant market, which needed no help as mutants were very easily obtained. The answer seems to lie in the use of *in vitro* culture techniques, and the Joint Division — through its Agriculture Laboratory at the IAEA's Seibersdorf Laboratories — has been active in exploring unconventional breeding methods for improvement of tropical crops. Palms, tropical fruits, cassava, yam, and cocoa have been among the crops studied. For example, cultures of banana tissues significantly enhance the effective use of mutation treatments. Cultivars of bananas aimed at acquiring disease resistance are being tested. One of these, called "Novaria" and developed at Seibersdorf, has just been released in Malaysia.

Animal production and health

Livestock are an important component of most farming systems. Internal parasites result in huge losses of animals worldwide, shown both through reduced growth and from needless deaths. Quite early research showed that some internal animal parasites could be "attenuated" by irradiation — that is made harmless — to provide vaccines against a number of killing parasitic diseases. The earliest FAO/IAEA co-ordinated programme in animal sciences in 1966 was devoted to the effective control of internal parasites in domestic animals.

The reproduction of animals has been another focus of research. The reproductive status of female animals can be determined by measuring the level of the hormone progesterone in their blood or milk using radioimmunoassay (RIA) with iodine-125 as a label. The Seibersdorf Laboratory has developed RIA kits especially designed for use under difficult conditions. Using this method, very successful FAO/IAEA programmes on buffalo production in Asia, sheep and goats in Africa, and llamas and alpacas in Latin America have given unique information on the reproductive behaviour of indigenous species and the types of livestock raised by typical small farmers. They have led to the identification of animals with superior performance, and the acceptance of new management practices to improve breeding efficiency.

DNA probes that are isotopically labelled (using phosphorus-32 or iodine-131), and immunoassay methods that are similar in principle, enable diagnosis of diseases, assist in conducting disease surveys, and monitor disease control programmes. The immunoassay test (enzyme linked immunosorbent assay— ELISA) is used to detect and measure antibodies to particular infections. It therefore can be used to establish the extent of major diseases, such as rinderpest (the cattle plague), babesiosis and brucellosis. Moreover, it can monitor the effectiveness of control measures such as drug treatment or vaccination.

ELISA has been highly successful. Kits especially designed at the Seibersdorf Laboratory have been supplied worldwide, with many millions of assay units sent out to different projects. A major use of ELISA has been in the rinderpest vaccination campaign in Nigeria, and, more recently, in the Pan African Rinderpest Campaign, which cleared rinderpest from 14 countries. *(See the following article.)*

Problems of nutrition also continue to command attention. Mineral deficiency or imbalance is often a problem in livestock, but frequently it is not easy to recognize that a problem exists until growth of the animals is seriously affected. Isotope methods for diagnosing copper, selenium, zinc, and phosphorus deficiency have provided a quicker way of determining the status of these essential elements, and were a feature of early FAO/IAEA work.

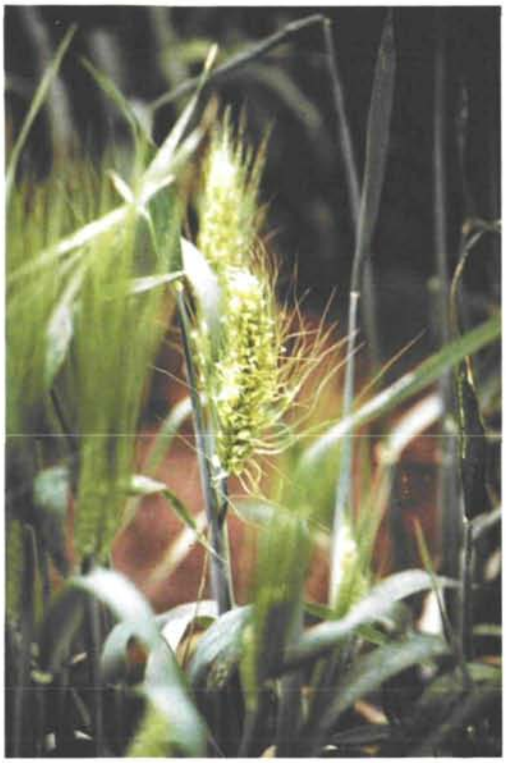
One co-ordinated programme used nitrogen-15 in studies of non-protein nitrogen sources, such as urea, as a supplementary feed for ruminants. This led to the use of cheap non-protein nitrogen to meet the protein needs of ruminants, because they can convert the inorganic nitrogen to protein.

Joint FAO/IAEA work in the 1980s focused on finding the best ways of using fibrous fodders like straw and crop residues, and byproducts of food processing industries such as bagasse, for feeding buffaloes, sheep, and goats. An artificial rumen, named Rusitec, was designed and used to study microbial degradation of feeds using isotope labelling. The acquired information has led to the formulation of new diets based on locally available feeds for ruminant animals in developing countries.

The worldwide scope of these programmes has contributed substantially to concepts now common among animal nutritionists in establishing the value of feeds and the nutrient requirements of livestock.

Insect control

There are major insect pests of crops, livestock, and humans whose impact is so great that the social development and economies of entire regions may be affected. They include the screwworm, which affects humans and warm-blooded animals (principally cattle), the



Facing page: Cattle farming in Africa; a farmer winnows rice, of which some 200 mutant cultivars have been developed; a market square in Guatemala; a scientist prepares an experiment at the Agriculture Laboratory in Seibersdorf; research at the Seibersdorf Laboratory on controlled release formulations of herbicides. *This page:* a close-up of a mutant of barley; a medfly trap in Central America. *(Credits: FAO; M. Maluszynski, IAEA; J. Marshall, IAEA)*

Mediterranean fruit fly (medfly), and the tsetse fly, which affects both livestock and humans.

Over the years, the FAO and IAEA have jointly convened eight major symposia on the application of radiation techniques to insect problems. The meetings have particularly influenced development of the Sterile Insect Technique (SIT). This technique involves rearing insects, which are then sterilized by radiation and later released in the infested areas. Their mates do not produce offspring, and with repeated releases the population is reduced and eradicated.

The medfly, *Ceratitis capitata*, is virtually ubiquitous wherever there is citrus and soft fruit grown. The economic consequences are profound as the fruit is seriously damaged, and consequently exports are greatly reduced. Researchers at the Seibersdorf Laboratories have developed artificial diets and highly successful rearing methods for the medfly, so that mass-rearing of millions of flies can be done cheaply. Though it sounds simple, it took a lot of research to make it so.

Two especially important developments occurred at Seibersdorf. The first was the creation of a genetic sexing strain of medfly in which the female pupae are white and the males brown, thus permitting easy separation and enabling the release of only male flies. A further very clever piece of research has involved the insertion of a differential heat-sensitive gene, induced by a chemical mutagen, onto the sex-determining Y-chromosome, by means of a radiation induced chromosome translocation; a technical "tour de force". The resulting medfly strain permits sex segregation at an earlier stage — the eggs are heated to 35°C, whereupon eggs carrying females are killed, while the males survive. This means that it is necessary to rear only half the larvae, thus halving food costs, a major expense of the SIT method. Moreover, releasing only males means that fruit is not punctured by females laying sterile eggs.

One of the big medfly success stories has been the eradication campaign in Mexico, for which the Joint FAO/IAEA Divison provided advice, training, and assistance in designing the eradication project and the fly "factory". In the end, a massive programme funded by Mexico and the United States could produce 500 million sterile flies per week. As a result the pest was eradicated from the infested area, and an enormous loss to the Mexican economy was prevented.

The New World Screwworm is a pernicious, unpleasant pest of all warm-blooded animals. Eggs are laid on the backs of animals and the resulting larvae bore through the hide into the flesh. In 1988, it was found that the insect had established itself in Libya, and an urgent national and international effort, co-ordinated by FAO and supported by IAEA, was mounted to prevent its spread to livestock and wildlife in North Africa, sub-Saharan Africa and the Mediterranean Basin. By 1992, eradication was achieved, preventing the enormous losses which would have occurred if the infestation had been allowed to spread.

Tsetse flies, *Glossina spp.*, effectively "sterilize" almost two-thirds of the land area of sub-Saharan Africa. The tsetse fly feeds on the blood of animals and transmits the Trypanosomas organism which is responsible for human sleeping sickness and the "Ngana" condition in cattle. About 50 million people are at risk in an area the size of the entire farmland of the United States.

Researchers at the Seibersdorf Laboratories have worked steadily towards making SIT a reality for tsetse, including development of methods of rearing on artificial membranes with a blood diet. At the start, it was not known if self-sustaining colonies could be kept for a long period in the laboratory, and still have progeny that would later function in the wild. This has now been achieved.

In Nigeria, an operation known as the BICOT pilot project was carried out by the FAO and IAEA in 1984-86. It successfully eradicated the tsetse fly from an area of 1500 square kilometers. At the present time, a number of pilot scale projects are being run to build upon the experience acquired during that project.

Agrochemicals and the environment

Public concern about the potential contamination of food is not new. Prior to 1964, the FAO had collected information on the amount of radioactivity from fallout found in soil, vegetation, and food. The data was reported to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). In 1969, these results were put into perspective at a seminar on Agricultural and Public Health Aspects of Environmental Contamination by Radioactive Materials jointly sponsored by the FAO, IAEA, and World Health Organization (WHO).

The Chernobyl accident revived the earlier international concern about the contamination of the environment by radioactive fallout. It led to a major FAO/IAEA report, *Radioactive Fallout in Soils, Crops and Food* in 1989. This was accompanied the same year by an international symposium on Environmental Effects Following a Major Nuclear Accident, which was convened by the FAO, IAEA, WHO, and United Nations Environment Programme.

A body of information exists to help evaluate the extent and magnitude of any future environmental contamination from radionuclides. The 1994 publication, *Guidelines for Agricultural Countermeasures Following an Accidental Release of Radionuclides*, will assist in devising methods of monitoring and limiting the short- and long-term effects on agriculture, food, and human health.

Nitrates in drinking water sources have become a political issue as well, as levels are sometimes close to or exceed WHO limits. A Joint FAO/IAEA Division programme in the 1970s used nitrogen-15 tracers to show beyond doubt that the nitrate found in the water table was almost exclusively due to agricultural inputs. The results were disseminated in a series of publications (1974, 1975, 1984) which have become standard references in the field.

The discharge of mercury waste to rivers and estuaries has caused localized outbreaks of poisoning in consumers of fish. Additionally, the use of organo-mercury compounds in agriculture as a seed dressing against seed-borne fungal diseases has caused the death of many birds and accidents to people. In collaboration with WHO and the International Labour Organization (ILO), the Joint FAO/IAEA Division has evaluated the impact of mercury on the environment. A monograph was issued which became a major source of information, and subsequently resulted in heavy restrictions on the use and release of mercury.

In the field of pesticides, radioisotope labelling has not only provided exceptionally accurate analysis of minute amounts (parts per billion) of pesticide residues, but has also provided the means to determine metabolic pathways, and the fate of the compounds in nature. Moreover, a considerable fraction of a pesticide-derived residue in soils and plant products cannot be extracted by conventional analytical solvents, and would therefore not be detected except by radioisotope labelling.

The fate of residues is a determining factor in deciding how a pesticide should be used, or on banning certain compounds as being ecologically harmful, or even determining that a compound that may be potentially harmful in one situation may be quite suitable for use in another.

For example, the use of DDT and lindane has been widely cut back or banned in temperate climates because of their persistence in the environment. A wide reaching study initiated by the Joint FAO/IAEA Division found that substances such as DDT and lindane dissipated much faster in tropical environments with high temperature and high humidity, so that local accumulation of residues was prevented.

One current approach of the Joint Division to a more environmentally friendly and efficient use of herbicides and pesticides is to make them available to the crop over a longer period, but in lesser concentration, by means of so-called controlled release compounds. These last for a longer time and release the active pesticide or herbicide over a longer period. Radioisotope tracers are invaluable in the research, development, and testing of such formulations.

Food preservation by irradiation

As much as one-third of the total world harvest may be lost due to spoilage and infestation on its way to the consumer. Food irradiation offers a safe and reliable way to reduce wastage. Decades of research have shown conclusively that there are no adverse effects from the consumption of irradiated foods. They do not become radioactive in any way nor does irradiation leave any harmful residues.

Food irradiation is valuable for disinfestation of stored products, such as grain, spices, dried fruit and vegetables; for the sprout inhibition of long-stored potatoes and onions, thus reducing the need for chemical inhibitors of doubtful safety; for the elimination of food-borne diseases, especially *Salmonella* in poultry, red meat, and seafood; for the disinfestation of tropical fruits from the fruit fly and other pests, for which it is an effective residue-free treatment; and for the extension of the shelf life of mushrooms, strawberries, and tropical fruits.

The FAO/IAEA Symposium on Food Irradiation at Karlsruhe in 1966 was a landmark in defining the possibilities of the technology. Nevertheless, from the strictly economic point of view, preserving food by irradiation has so far made only modest impact, despite its advantages. However, the development of enabling technology and legislation has made considerable progress during the last 30 years, and the work of the Joint FAO/IAEA Division has been largely responsible for this.

Despite economic handicaps and the resistance of some consumer groups, the number of facilities for food irradiation has steadily grown, and there are now about 65 facilities worldwide, of which about 50 might be called commercial.

During the period 1971-81, the FAO, IAEA, and WHO appointed groups of experts to evaluate the studies of the wholesomeness of irradiated foods. As a result of the stimulation and co-ordination of the Joint Division, it became possible in 1983 for the Codex Alimentarius Commission to adopt and publish an international standard for food irradiation.

At present, an International Consultative Group on Food Irradiation (ICGFI) operates under the aegis of the FAO, IAEA and WHO, with the FAO/IAEA acting as its Secretariat. It evaluates global developments and provides Member States with advice. Training has always been an integral part of the effort and the first FAO/IAEA course was held in Michigan, in the United States, in 1967 and was the first of its kind. Later, several hundred persons were trained during the 10 years of an international food irradiation project in Wageningen, Netherlands. Today, training is encouraged by ICGFI, which organizes Irradiation Process Control Schools, where certificates are earned by successfully trained operators. Its curriculum is being endorsed by an increasing number of food control authorities.

Training and research for development

Training and applied research via co-ordinated programmes and the Seibersdorf Laboratory have always been a prominent feature of Joint Division activities. During the past 30 years, there have been 2200 participants in 122 inter-regional training courses. Moreover, 2609 IAEA fellowships have been awarded in agriculture; 380 of the fellows worked directly at Seibersdorf. From the beginning, the Agriculture Laboratory at Seibersdorf has been central to the Joint Division's work and impact. Without it, some of the most successful programmes could hardly have taken place, as it has done pioneer work not done elsewhere. Its role has been to develop methods and test them, to pursue new lines of approach, and to perform the essential backup for the co-ordinated research and other field programmes.

Originally housed in a pre-fabricated building bought for US $25 000 earned from a contract (how could a building be so cheap?), the agriculture laboratory has grown to a useful, though still too small, size as a wing of the main laboratory.

Similarly, the FAO/IAEA training courses at Seibersdorf used to cause great internal strains because of the lack of space. A new training centre has greatly improved conditions for course participants, fellowship trainees, and the Laboratory staff alike. It has been a fine investment in the future. ❐

From 17-21 October 1994 in Vienna, the FAO and IAEA are jointly convening an International Symposium on Nuclear and Related Techniques in Soil/Plant Studies on Sustainable Agriculture and Environmental Preservation.