The IAEA and the green revolution

From research laboratories to farmers' fields, nuclear techniques are making a difference

by Björn Sigurbjörnsson and Leo E. LaChance

The term "green revolution" originally referred specifically to a few high-yielding cereal varieties developed in the 1960s that, together with more use of fertilizers and pesticides, started a food production revolution, primarily in Asia. A number of chronically food deficient countries suddenly became self-sufficient in cereals, accumulating large reserves and eventually becoming net food exporters.

Looking back, it is clear that this was the beginning of an agricultural revolution that in a mere two decades negated the doomsayings and predictions of widespread food shortage of the 1970s. Many places in the world still have serious malnutrition, but generally speaking this is often due to natural catastrophies, political factors, and other reasons, and not from a lack of food production technology. Food production has outpaced population growth. The amazing progress is primarily due to advances in plant breeding and crop husbandry based on vastly increased inputs.

From the very beginning of this green revolution, nuclear techniques played a significant role. They provided an added dimension to agricultural research and development which in many cases proved to be crucial. Research based on the unique properties of radioactive and stable isotopes of plant and animal nutrient elements has greatly accelerated our knowledge of plant physiology and crop nutrition. It has provided an essential base for any progress in crop husbandry and has added to our knowledge of animal nutrition, reproduction, and disease diagnosis — prerequisites for raising animal productivity.

Ionizing radiation has proved invaluable for enhancing genetic variability in crop plants. It induces both deleterious and beneficial mutations and permits plant breeders to utilize new genes and gene combinations to produce crop varieties that are disease resistant, better adapted, higher yielding.

Through the same mechanism, ionizing radiation causes sterility in insect pests, thereby curtailing their reproduction, and sterilizes or kills pathogens and organisms that cause food-borne disease and spoilage.

Thus, alone or in combination with other advanced technologies, the various applications of nuclear technology have contributed to this revolution at every stage of the food production path — from soil, water, and seeds through plant and animal development, and the protection of stored foods until they reach the consumer's table. At the same time, these tools have helped in research to protect the environment in response to the vastly increased use of potentially harmful chemicals.

Agency's involvement

Soon after the IAEA was founded in 1957 an agricultural expert was hired. He started the agricultural programme by placing research contracts with some of the world's foremost users of radiation-induced mutations in plant breeding. Five years later, the first co-ordinated research programme was organized using isotopic tracers to help Asian rice producing countries establish more efficient fertilizer practices. Other programmes followed, revealing better ways to place and time fertilizer applications in wheat and maize fields and eventually branching into very successful programmes to enhance nitrogen fixation of legumes and to improve irrigation practices through use of isotopes.

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Photo above: Radiation-induced mutant of barley has short, erect, and dense spikes.

By 1964, programmes had also been started in entomology, animal science, and food preservation. The supporting activities of the Seibersdorf Laboratories were establishing themselves as the very backbone of the Agency's agricultural programmes and, in retrospect, as the key to the great success of these programmes in developing countries. *(See the article on the Seibersdorf Laboratories in this edition.)*

In that same year, 1964, the Agency's programme underwent a profound change which was to prove fundamental in ensuring the effectiveness and relevance of the programme to food and agricultural development worldwide. This was the agreement between the IAEA and the Food and Agriculture Organization (FAO) of the United Nations to establish a joint division responsible for all UN activities in this field. This enabled the Agency to interact directly with the agricultural research efforts from which the green revolution sprang.

This article provides only a few examples of the additional achievements of the six sections that comprise the Joint FAO/IAEA Division:

Plant breeding

The Plant Breeding and Genetics Section has developed effective standardized methods of mutagen treatment of seeds and plant parts, as well as methods of assessing radiation effects and isolating and testing promising mutants. Thus, the FAO/IAEA *Mutation breeding manual* has been used by plant breeders the world over for the last 20 years and has significantly contributed to the great success of induced mutant crop varieties.

The unique contribution of induced mutations to the green revolution is their ability to repair deficiencies in the highest yielding and best adapted varieties. The new superior varieties developed using induced mutations are either used directly in farmers' fields or used in further breeding programmes. As a result, induced mutations are, for example, carried in the genotypes of many of the best varieties of barley grown in Europe, durum wheat (pasta) grown in Italy, rice grown in California, as well as in some of the most productive crop varieties grown throughout the developing world. In many cases, the original radiation seed treatment was carried out at the Seibersdorf Laboratories, the breeders were trained by the Agency, and the superior varieties resulted from work carried out within Agency research contracts or technical co-operation projects. At the present time, nearly 1000 crop varieties derived from radiation-induced mutations are grown worldwide on several million hectares. If all varieties with mutants in their parentage are counted, the number reaches possibly tens of millions. The annual economic gains are measured in billions of dollars.

Soil and water

Isotopes provide the only direct means for distinguishing native-soil from fertilizer-derived nutrients in plants. This then makes it possible to assess how efficiently plants use an applied nutrient source in order to recommend the best ways to increase the efficient use of costly fertilizers. In some cases, this results in the application of minimum amounts of fertilizer for maximum plant growth.

In a co-ordinated research programme of nine developing countries using fertilizer labelled with phosphorus-32 in rice soils, it was found that the placement of phosphate fertilizers on the surface of the soil, or worked into the surface soil, was more than twice as efficient in supplying phosphorus to plants than when it was placed 10 centimeters deep between rice rows. This finding permits a reduction in fertilizer use by more than one-half without loss of yield.

Fertilizers labelled with the stable isotope nitrogen-15 were used to demonstrate that deep placement (5-15 centimeters) of nitrogen fertilizers in soil gives higher

Scene from 1977 training course in India sponsored by the IAEA, FAO, and Swedish International Development Agency, where mutation breeding of sorghum with improved disease resistance drew keen interest.

An essential source of protein in diets of millions of people, pulses have been a focus of the Agency's plant breeding programmes for 30 years. About 80 improved cultivars of 13 different species derived from radiation-induced mutations have been given to farmers for improved food supplies.

uptake efficiencies than surface applications. The data from 13 developing countries showed an increase of about 32% in nitrogen uptake efficiency by plants when the fertilizer was placed at this depth, compared to surface application. One participating country which followed fertilizer recommendations based on these results reported that US $30 million were saved in one year from reduced nitrogen fertilizer applications.

Methods for using nitrogen-15 in the field to distinguish biologically fixed nitrogen in plants from the nitrogen derived from soil was developed largely by staff of the Agency's Soil Fertility, Crop Production, and Irrigation Section and its Seibersdorf Laboratories.

Large differences have been found among grain legume species in their abilities to fix atmospheric nitrogen. For example, while one type of bean plant, *Vicia faba*, is able to satisfy about 70% or more of its nitrogen requirement from nitrogen fixation, another type, *Phaseolus*, a common food grain legume, derives about 30% or less from it. A co-ordinated research programme was subsequently initiated to breed for higher nitrogen fixation in *Phaseolus* and there are signs that this will be possible. A slight increase in nitrogen fixed in this common grain legume would result in a significant reduction in the use of nitrogen fertilizer worldwide.

A grass pasture in Uruguay offers an example of possible savings: The inclusion of white clover there resulted in the pasture fixing about 120 kilograms nitrogen per hectare from the atmosphere within 6 months. This is equivalent to saving about 250 kilograms of urea fertilizer per hectare worth about US $73 per hectare over 6 months.

Livestock

Most developing countries in tropical and subtropical regions suffer from shortage of livestock products, not because of any serious lack of livestock, but because animals there are much less productive than those in temperate regions.

The activities of the Animal Production and Health Section are aimed at raising animal productivity by improving nutrition, reproductive capacity, and diagnosis of disease in affected regions. One method advanced by the Section is the development of supplemental feeding strategies: Cheap local sources of crop and animal residues (for example, maize stover, sugar-cane bagasse, fish meal, poultry manure, and alkali/ammonia-treated straw) and agro-industrial by-products (such as urea) are included in the diet. Livestock receive a more balanced input of dry matter, energy, protein, minerals, and vitamins, and so their productivity improves. The adequacy of the supplemented diet is assesed *in-vitro* by the use of isotopic techniques. The supplemented material — identified with a radioactive marker such as carbon-14, phosphorus-32, iodine-125, or hydrogen-3 — is passed through an artificial rumen apparatus and its influence on the rumen fermentation products, microbial, and by-pass protein is assessed before on-the-farm testing. This screening of feed supplements before use in livestock feeding trials has increased the rate at which new or modified supplements can be tested and has dramatically reduced the costs.

Radioisotopes such as hydrogen-3 and iodine-125 have been used to help identify and measure hormones which facilitate metabolic studies in order to enhance animal reproduction. Isotopes have been used to develop radioimmunoassay (RIA) and enzyme immunoassay (ELISA) tests that constitute some of the most effective routine diagnostic procedures concerned with reproductive disorders, therapeutic needs, toxicological evaluation, and residue studies.

The use of nuclear technology has played a significant role in the formulation and monitoring of hormones necessary for embryo transfer, embryo sexing, and other enhancements of the reproductive process.

Development of modern livestock systems in both developed and developing countries has been greatly aided.

Radioisotopes and radiation are also used in animal disease diagnosis and control. The Section has supported the application of radiation for production of animal vaccines. The most spectacular development has been the introduction of an irradiated vaccine against lungworm in cattle, a seasonal parasitic disease which, before the use of this vaccine, gave rise to major losses in yearling animals. Since its introduction some 15 years ago, the vaccine's use — many millions of doses — testifies to its enormous value to the livestock farmer.

Insect control

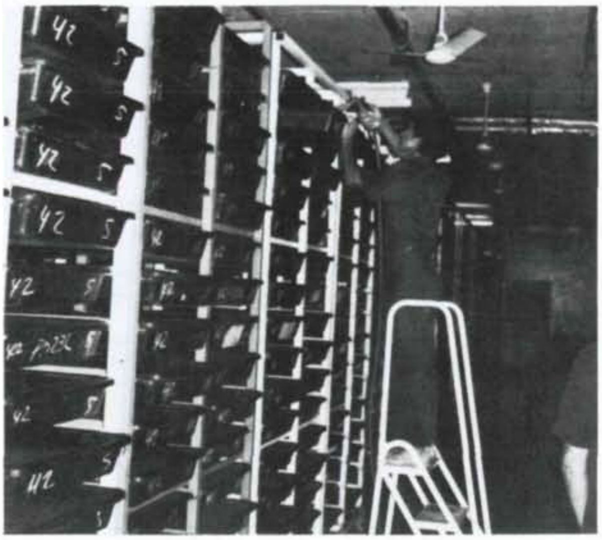
The Insect and Pest Control Section is primarily involved in assisting countries to develop practical applications of the sterile insect technique (SIT) as an effective, inexpensive, and environmentally safe method of insect eradication or control. Emphasis has been placed on the Mediterranean fruit fly (medfly) and several species of the tsetse fly, which transmit the disease trypanosomiasis to cattle and humans. SIT requires rearing large numbers of insects which are then sterilized with gamma radiation and released in overwhelming numbers in the field where they mate with wild insects. These matings produce no progeny and thus lead to a reduction and eventual eradication of the insect population. Thus, mass-rearing is the heart of the operation. It has been used successfully in eradication programmes against the medfly and the tsetse fly in many developing countries.

In Mexico, mass-rearing technologies co-operatively developed by the FAO and IAEA have been scaled up to rear more than 500 million medflies per week. They are sterilized with gamma radiation and released aerially. The project successfully eradicated the medfly from Mexico within a few years. The sterile flies are now being used to eradicate the medfly from Guatemala and protect Mexico from reinvasion. Savings to harvests are estimated in hundreds of millions of dollars per year.

Rearing tsetse flies is very different from mass-rearing medflies. Tsetse flies produce one offspring every 9 or 10 days, thus reproducing very slowly, and their populations in the field are very low indeed compared with other insects. Rearing the flies was first done on goats, rabbits, and guinea pigs. Now artificial membranes using blood collected in local abbatoirs are used. This technology was used in central Nigeria and led in 1987 to successful eradication of a species of tsetse fly from an area of 1500 square kilometres.

Environmental protection

The Agrochemicals and Residues Section directs its efforts at increasing the safety of fertilizer and pesticide use and reducing harmful residual effects, which may be the result of improper as well as proper use of these agrochemicals. As their massive inputs are a prerequisite for high-yielding crop varieties of the green revolution, effective assessment of their fate and significance in the agricultural environment is essential for proper farm land management.



As part of Mexico's SIT project against the medfly, eggs were seeded on trays of larval diet and placed in a room at constant temperature and humidity for 7 days so the flies fully developed.

By using nuclear techniques to aid studies of pesticide residues, it has been shown that the problem with residues in the tropics may not be as serious as previously thought, provided some basic rules for application are followed. The high average temperatures and humidities encountered in most developing countries favour much higher dissipation rates of pesticides than are expected for temperate climates. Although some enhanced microbiological breakdown is demonstrated, much of the dissipation is due to simple volatilization from plant and soil surfaces.

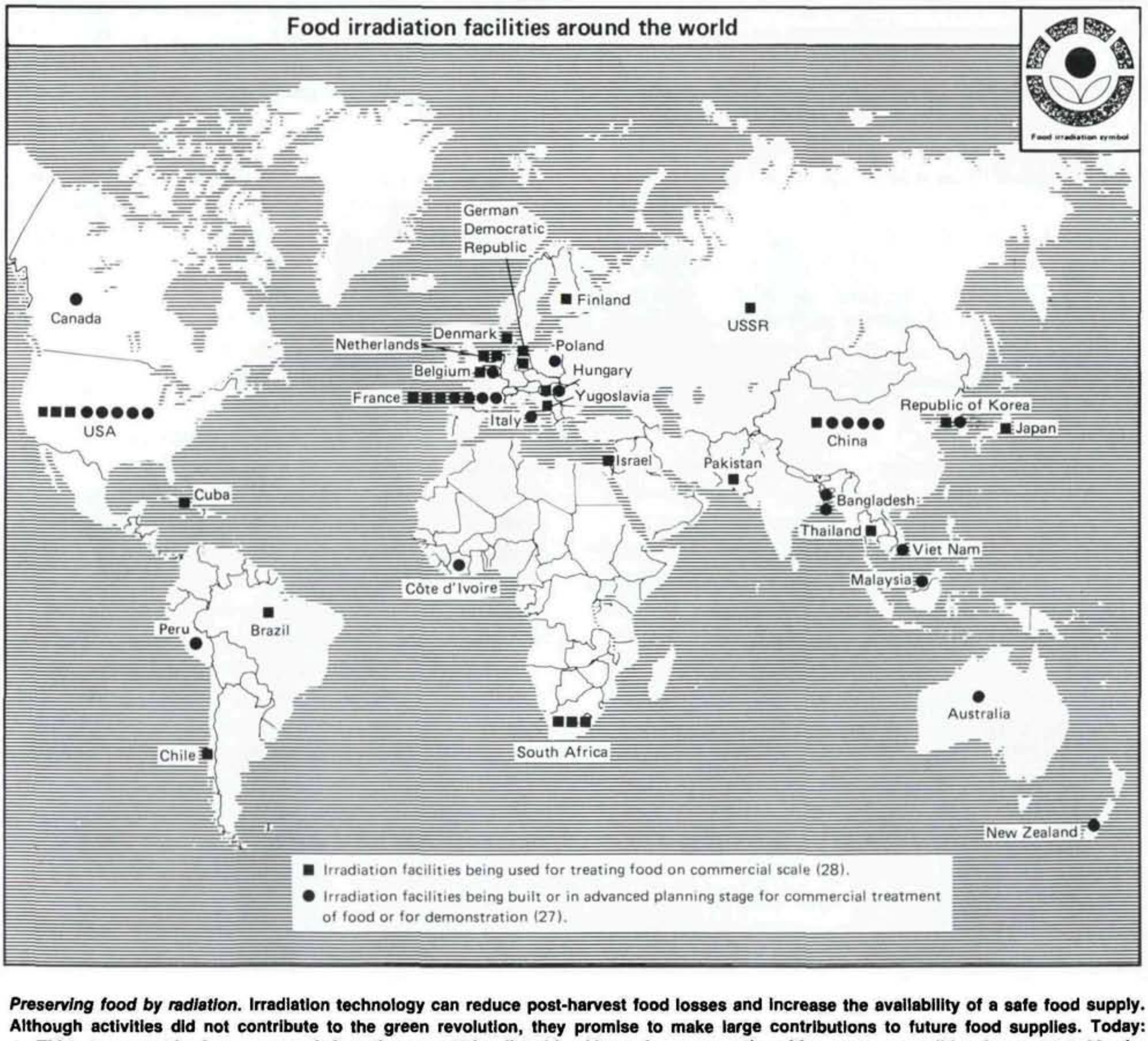
Currently the Section is playing a dominant role in determining the environmental acceptability of potentially harmful, but highly persistent and economically viable, pesticides such as DDT and lindane. Co-ordinated research is being conducted mainly in tropical regions, with a view to measuring dissipation and degradation rates of DDT and similar chemicals. Preliminary results have indicated that DDT would dissipate in major areas of Kenya, India, and Sudan at rates which would preclude local accumulation of residues in soil, plants, or wildlife.

One other activity looks to increase efficacy of a range of pesticides and thus reduce the application rate by controlled release formulations. An example is the embedding of long-lasting insecticides, such as Endosulfan in polymers, to be used as targets for tsetse flies in tropical Africa. The object is to reduce the fly population by attracting the flies to the targets where they will receive a lethal dose of insecticide. It is believed that along rivers it may be possible to drastically reduce the fly population, with very little impact to the local environment.

The years ahead

Requirements for increased production of high-quality food will continue. The world's population has just passed the 5-billion mark and shows little signs of slowing down. The future challenge is to sustain the world's food production at lower cost, with reduced inputs and more concern for the environment. Further improvement in crop breeding and crop animal husbandry call for even more sophisticated technologies.

Vistas opened by new biotechnologies and genetic engineering will undoubtedly accelerate progress. Almost every aspect of these new technologies relies on the use of isotopic tracers or ionizing radiation. Nuclear techniques have gradually become routine tools in the agricultural laboratories of developed countries and some advanced developing countries. Our aim is to assist the others in making routine use of these techniques in agricultural research. Nuclear techniques are rarely alone in research and development. They are increasingly used as an integral and essential part in the overall applications of modern technology in advancing food production and sustaining the "green revolution" for years to come.



Preserving food by radiation. **Irradiation technology can reduce post-harvest food losses and increase the availability of a safe food supply. Although activities did not contribute to the green revolution, they promise to make large contributions to future food supplies. Today:**

- **Thirty-two countries have approved altogether over 40 irradiated food items for consumption either on an unconditional or restricted basis.**
- **Nineteen countries are using 25 irradiation facilities for processing selected food items on a commercial scale. Ten other countries are constructing or are in an advanced stage of planning additional facilities for processing food and non-food items. It is anticipated that at least 25 countries will use some 50 irradiation facilities for processing food items by 1990.**
- **The International Facility for Food Irradiation Technology (IFFIT) is a joint project of FAO, IAEA, and the Ministry of Agriculture and Fisheries of the Netherlands. To date, IFFIT has trained over 200 scientists and officials from more than 40 countries.**
- **The International Consultative Group on Food Irradiation (ICGFI), sponsored by FAO, IAEA, and the World Health Organization (WHO), evaluates global developments and provides a focal point of advice and information in the field to Member States and the organizations. Twenty-six countries are members of ICGFI and are contributing either in cash or in kind to its programmes.**