international atomic energy agency

addendum to the
agency's annual report
to the
economic and social council
of the
united nations for 1970-71

# nuclear techniques and the green revolution

the joint programme
of the
food and agriculture organisation
of the
united nations
and of the
international atomic energy agency
on nuclear techniques in food
and agriculture

# CONTENTS



Printed by the IAEA in Austria - June 1971

# WHAT IS THE GREEN REVOLUTION?

In an age beset by social and political revolutions, the Green Revolution deals with the most basic of human needs and offers scope for better balance between the growing population and its food requirements. This report takes a close look at how nuclear techniques are being utilized in modern agricultural research to augment the Green Revolution.

The Green Revolution is basically the growing of new, higher yielding cereal varieties, particularly wheat and rice, in the developing countries of Asia and Latin America. Many of the new varieties were developed by plant breeders in the Philippines, the United States of America and in Mexico, among whom is Norman Borlaug, who was recently awarded the Nobel Peace Prize for his work. The Green Revolution has produced striking results: in Mexico, where the Green Revolution began, wheat yields have risen from 550 kg per hectare in 1950 to 2530 kg in 1970. Five years ago, the Philippines imported a million tons of rice annually, but now expects to be an exporter of rice in the near future. The introduction of high-yielding grain varieties into West Pakistan has been the main factor in increasing wheat production there by 71% and rice production by 62%. In the period 1967—1969 wheat production in India rose by 50%, and the rice crop in Ceylon by 34%. Although the Green Revolution, so far, has been limited to a few cereals and a few countries, many other countries are now beginning to feel its impact.

By transforming shortage and famine so dramatically into sufficiency and even local surplus, this breakthrough is forcing upon much of the developing world a new recognition of the need for a modern agricultural technology. As is shown in more detail later in this report, the new cereal varieties cannot realize their potential for high yield without careful cultivation and management. Modern fertilizer and irrigation practices and protection of crops against diseases and pests are thus indispensable. When the grain produced suddenly exceeds the farmers' own requirements, a whole new system may have to be developed for storing, selling, shipping and distributing that grain.

These new demands on the economies of developing countries have given an entirely different meaning to the term "Green Revolution". Indeed, the introduction of high-yielding cereal varieties into the Third World has had economic, social, political and cultural effects far beyond the expectations of the agricultural scientists who developed the new grains. In the broadest sense, the Green Revolution demands national policies of land reform, agricultural production credits and rural employment and, in consequence, it can lead either to national prosperity or to chaos.

The eminent Swedish plant breeder, Professor Åke Gustafsson, stressed recently that the Green Revolution marked only a beginning — a technological breakthrough. What we are really concerned with is a "Green Evolution" maintained by agricultural research and technology and accompanied by economic, social and political adjustments.

This report deals only with the additional scientific contribution that nuclear techniques are making and can make to sustain and expand the Green Revolution. In this sense it complements other reports dealing with the contributions of the non-nuclear techniques, which are primarily responsible for the Green Revolution.

# WHAT ARE NUCLEAR TECHNIQUES?

Modern science utilizes three main groups of nuclear techniques:

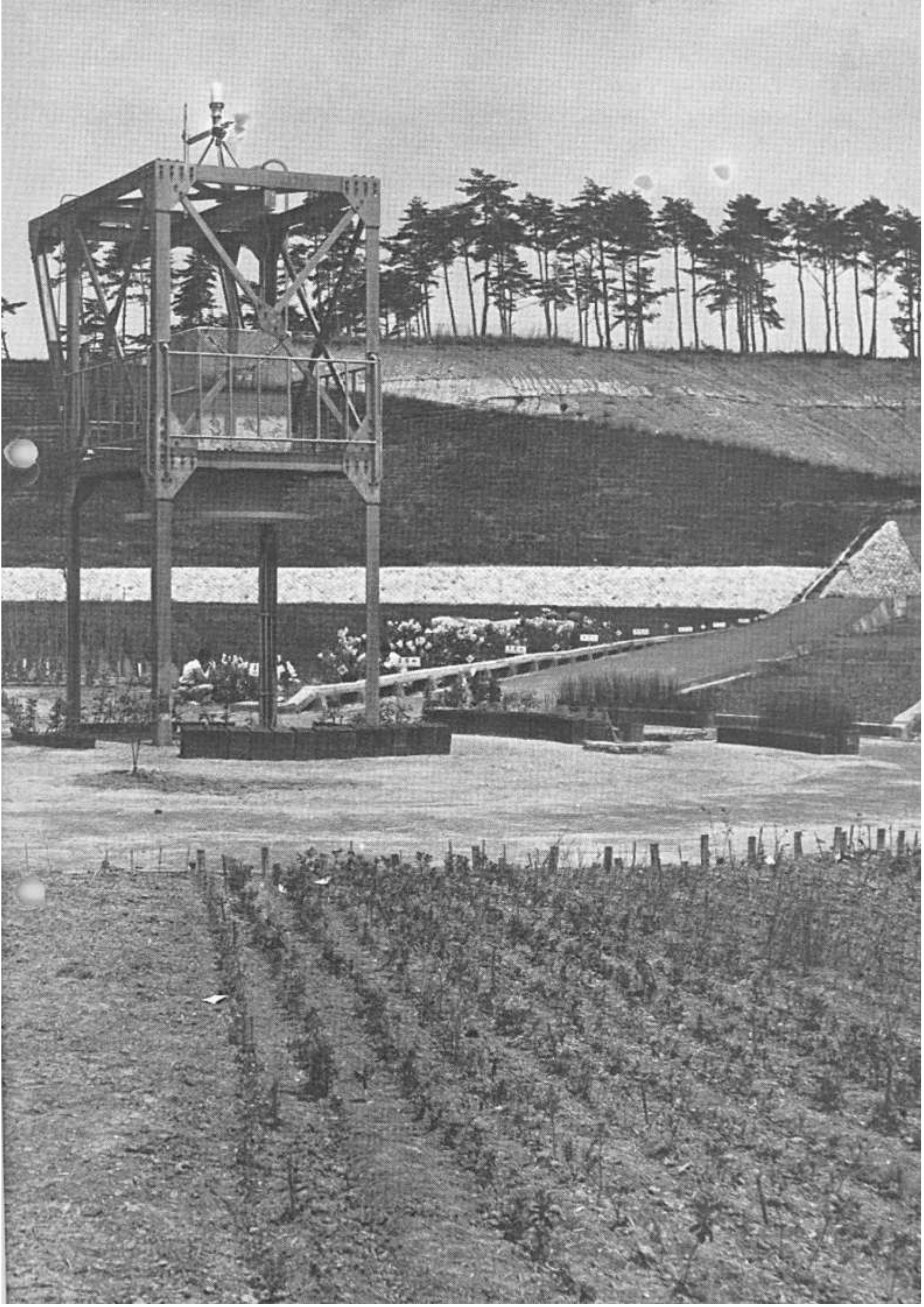
## RADIATION

Radiation can be produced from radioactive isotopes (e.g. gamma rays from cobalt-60), from X-ray machines or from nuclear reactors and accelerators which generate neutrons. Such radiation can be used in agriculture to induce mutations in plants by re-arranging the basic building blocks of a plant chromosome, the genes. Other applications include controlling insects through sterilization, preserving food and producing livestock vaccine from radiation-attenuated parasites.

## TRACERS

Most chemical elements have isotopic forms, differing from each other in the weights of their nuclei. Isotopes of a single element, however, have the same chemical properties. Some isotopes are radioactive, i.e. they emit radiation. For example, radioactive phosphorus behaves chemically in the same way as ordinary phosphorus, being different from it only in atomic weight and in its radioactivity. This radioactivity can be located and measured by radiation detectors, so that the movement and location of a phosphate compound can be traced if radioactive phosphorus has been incorporated into the compound. In a plant — in its leaves, for instance, or in its fruit — the amount of the phosphate compound that is taken up from the soil can be measured together with its distribution throughout the plant. There are now literally hundreds of "radioisotope tracer" techniques, used not only in agricultural research but also in medicine, biology and engineering. A second type of tracer does not depend on a radioactive isotope but only on a difference in atomic weight (mass) between the most common form of the element and the heavier or lighter isotope. This tracer technique requires more elaborate detection systems, but stable mass isotopes are used in much the same

Gamma rays from the radioactive isotope cobalt-60 contained in the tower are used to produce mutations in plants growing in this "gamma field" in Japan. Photo: IAEA



way as radioactive isotopes. Thus, nitrogen-15, an isotope heavier than the most common nitrogen isotope, is used as a mass tracer in studying the uptake from the soil and utilization by the plant of nitrogen fertilizer.

## ACTIVATION ANALYSIS

If a sample under study (e.g. plant tissue) is irradiated with neutrons in a reactor, it becomes radioactive. The characteristics of this induced radioactivity enable the elements in the sample to be identified and quantitatively measured. This technique, called neutron activation analysis, is used to detect extremely small quantities of certain elements found in plant and animal tissue, for example those associated with pesticides.

# HOW ARE NUCLEAR TECHNIQUES BEING APPLIED IN THE GREEN REVOLUTION?

Nuclear techniques have already contributed to improving the crops upon which the Green Revolution depends. Some of the new high-yielding varieties have been — and are being — derived from radiation-induced mutations. Induced mutations may also be used to improve the food quality of the crop so that nutritional value may be combined with high yield. Similarly, radiation can produce mutants with resistance to plant disease. Finally, radiation can be used to control a number of insect pests by the "sterile-insect release technique", in which laboratory-reared insects, sterilized by radiation, are released in large numbers to swamp the "wild" population, thus drastically reducing the next generation.

The new high-yield varieties require efficient soil and crop management, plentiful water and properly applied fertilizer. Tracer techniques are valuable in determining the best practices in fertilizer and water management. Tracer and activation techniques also help the scientist to follow the paths of pesticides and other pollutants in the environment and the food chain.

## THE GREEN REVOLUTION DEPENDS ON HIGH-YIELDING VARIETIES

The high-yielding grains (rice and wheat) of the Green Revolution have a short, stiff straw. Stated simply, this means that added fertilizer results in more grain instead of more stalk or leaf and that the plant is more resistant

The lodging-resistant rice mutant line in the background was produced by mutation breeding in Taiwan from the parent variety Pai-mi-fen (foreground), which here shows extreme lodging. Photo: H.W. Li


Pai-mi-fen

to wind and rain. The short and stiff straw of the "miracle" varieties originated from naturally occurring mutations. Mutations occur spontaneously but very infrequently in nature; radiation and chemical mutagens produce the same results but vastly accelerate the natural process. The characteristic short, stiff straw is now known to be easily and frequently produced by radiation treatment.

The Japanese rice variety Rei mei, with its short, strong straw induced by gamma-radiation, illustrates the value of this technique. It has become one of the leading high-yielding rice varieties in Japan. Similarly, short-straw mutations of durum wheat (the source of pasta) are replacing traditional varieties in Italy and have performed well throughout the Near East.

In 1964, the IAEA and FAO (Food and Agriculture Organization of the United Nations) combined their activities by founding the Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture. Since then, the Joint Division has conducted several co-ordinated programmes[1)] on mutation plant breeding for crop improvement. One of the first of these, a research programme on the use of mutations induced in rice, was implemented mainly by institutes in South East Asia and led to several new varieties. In the Philippines, for example, several new mutant lines have been developed, three of which are about to be released to farmers. They are higher yielding and/or shorter in stature, earlier in maturity, and more resistant to lodging than the original variety. In east Pakistan, four mutant lines (developed from a "miracle" variety, IR-8) matured earlier and were better adapted to local conditions; two of these are expected to be released soon to growers. In India, the favourable grain characteristics of indica rice were induced in the japonica plant type, a feat which had been attempted without success for 20 years through hybridization of the two types.

About 100 crop varieties derived from induced mutations have now been released to growers. It is estimated that these varieties are being grown on over five million hectares and represent crop production valued at over a thousand million dollars annually.

Emphasis on high yield from the new cereal varieties has sometimes been at the cost of quality. Food quality is mainly determined by the following factors:

(a) Nutritional value, i.e. the content of protein, essential amino acids, viatmins and minerals available for body growth and development;

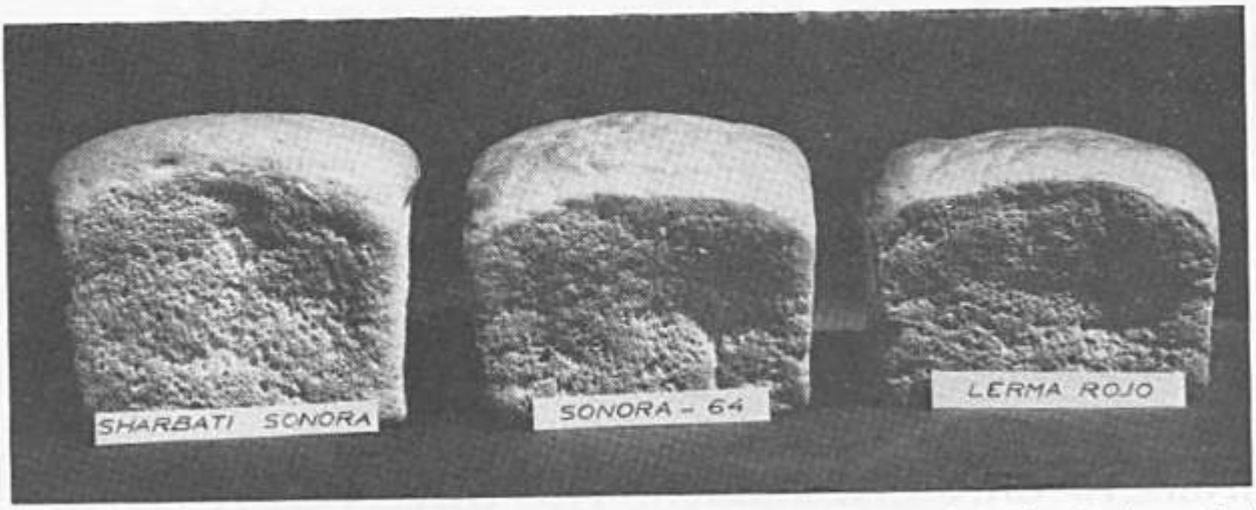
(b) Storage and processing characteristics; and

(c) The complex of subtle characteristics such as taste, aroma, texture and appearance so important to the consumer.

The "miracle" rice varieties introduced early in the Green Revolution were sometimes deficient in food quality. Many people in India and South East Asia found that the rice was too gluey and stuck to their fingers when they ate it. As a result, the new rice was often sold at a discount for cattle

---

1) A description of the co-ordinated research programme activity is given in the Annex.




The better baking quality of the mutant wheat Sharbati Sonora is shown by the larger loaf at left. The parent Mexican variety (middle) and another Mexican wheat (right) grown in India produce smaller, more dense loaves. Photo: Indian Agricultural Research Institute

fodder. In India, the red wheats introduced from Mexico were unattractive to consumers who were accustomed to using amber-coloured grain to make their chupatties (unleavened brown bread). A non-sticky high-yielding rice will soon be grown in the Philippines and a high-yielding amber-coloured wheat has been on the market in India since 1967, both produced by radiation-induced mutations. In response to world-wide interest in new and better sources of protein, the mutation plant breeder is attempting to develop crop varieties with higher protein content and/or higher content of certain essential amino acids (such as lysine). It has recently become clear that mutations, including those induced by radiation, can markedly increase the amount of protein and essential amino acids. A problem that still remains to be overcome is that of raising the yield simultaneously with protein content.

The Joint FAO/IAEA Division is conducting a co-ordinated research programme to improve protein in cereals and legumes. Participating scientists have already reported encouraging results in improving the protein content of rice and barley and in improving high-protein crops such as beans and peas. Rice mutants with significantly higher protein content have been produced in Japan, and, in Pakistan, protein content has been raised in "miracle rice". In Japan, radiation treatment of a single rice variety has resulted in a series of mutants with a wide range of protein content duplicating the entire range found in nature.

Nuclear techniques are being developed for rapid analysis of plant material to select mutants of high protein and essential amino acid content. Since changes in nutritional quality cannot be detected visually — as opposed to characters such as short straw — the plant breeder must use assay methods based on chemical, physical, or biological techniques. Such analyses may be greatly speeded up by using radioisotopically tagged compounds or by neutron activation.

Radiation is also used to breed new mutant varieties that are more resistant to insects and disease, thereby supplementing the natural pool of genetic resistance already available. Examples of disease resistance induced through radiation are rust-resistant wheats developed in Argentina, a blotch-resistant wheat in Kenya and a blast-disease-resistant rice in Korea. Plant breeders in many countries are devoting their efforts to combatting the manifold forms of plant disease. This is an unremitting struggle, but over the years it has prevented crop losses amounting to millions of dollars. FAO and the IAEA are launching a co-ordinated research programme on breeding for disease resistance, including the use of induced mutations.

## INSECTS CAN UNDERMINE THE GREEN REVOLUTION

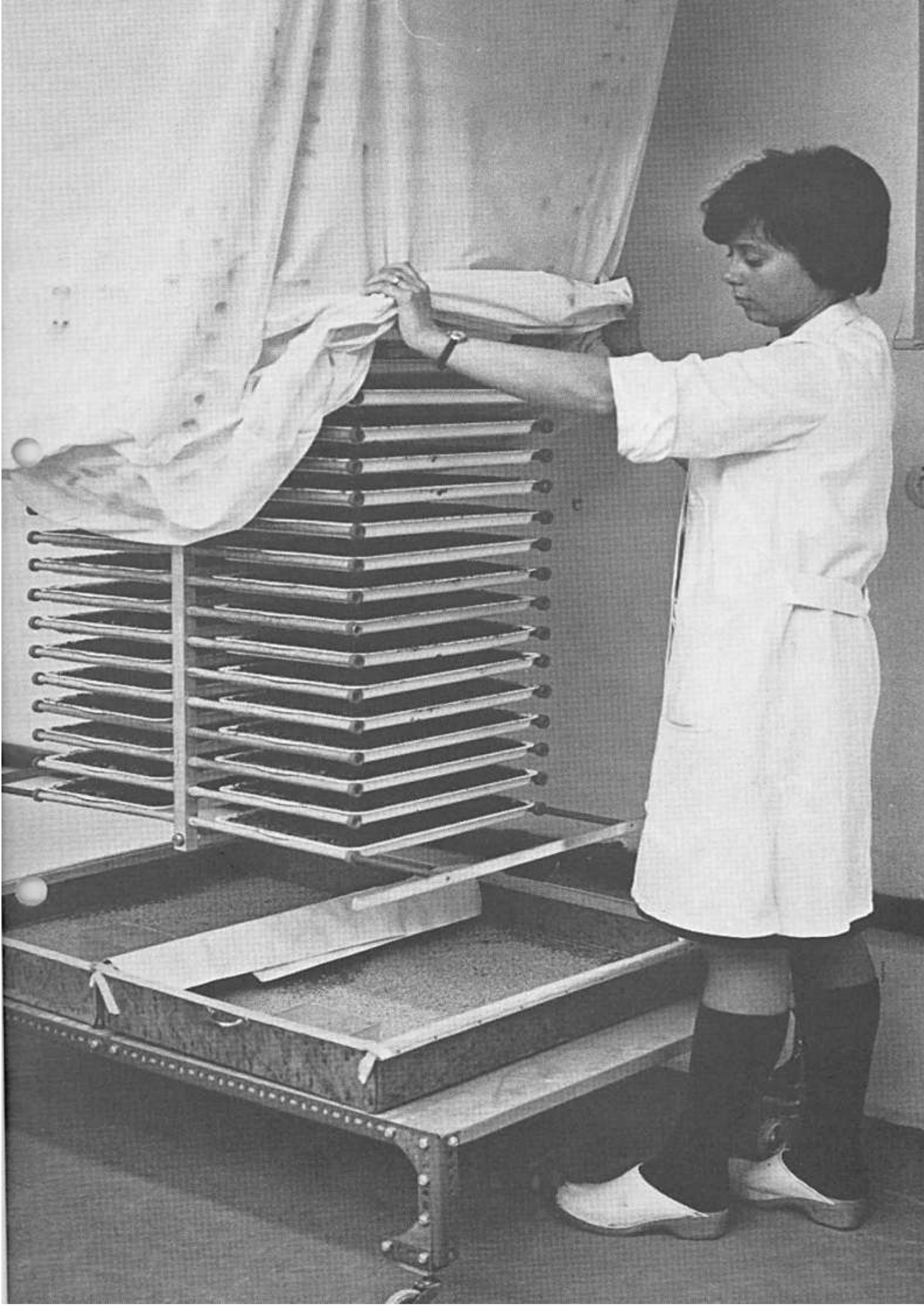
If the immense losses caused by insects were only partially avoided, crop yields would increase substantially. Insect pests may be controlled under certain conditions by using radiation as a means of sterilizing them. The radiation doses used do not affect the ability of males to comptete for females, so that they can mate normally after their release into the wild population. However, the eggs resulting from such matings do not hatch. The sterile-insect release technique has proven to be effective when used in a crop area isolated from other infested areas (e.g. by bodies of water, mountains, deserts, or other crops) and when the insect population is at a relatively low level (as at certain times of the year or following insecticide application).

One example of sterile-insect release is the large-scale feasibility trial conducted against the Mediterranean fruit fly (Medfly) in Central America in 1969. The Joint FAO/IAEA Division was responsible for the technical supervision of the project. Over a thousand million flies, mass-reared in the laboratory and sterilized with gamma radiation, were released from aircraft above a 48-square-kilometer test area, where there were citrus trees heavily infested by the pest. Since the ratio of sterile Medflies to wild flies was high, the wild flies mated more often with sterile ones than with each other. The population of the next generation was drastically reduced, thus demonstrating the feasibility of this technique.

The Joint Division is promoting the sterile-insect release technique through co-ordinated research programmes concerning a wide range of insects, including the rice-stem borer and other moths which attack cereals.

Interest in the sterile-insect release technique has been quickened by growing concern about the effects of chemical pesticides, such as DDT, on the environment. There is thus a great incentive to develop biological methods (e.g. with hormones and parasites) aimed specifically against given pests and

Insect pests may be controlled by release of large numbers of radiation-sterilized insects into the natural population. The photo shows a part of the mass rearing facility in the IAEA laboratory. Photo: IAEA



which are unlikely to harm any other living organism, including man. Of these biological methods, the sterile-insect release technique has shown considerable promise in controlling certain insect populations.

Nevertheless, pesticides and fungicides are essential if the agriculture of a developing country is to reach its full potential without being hindered by plant and animal pests and by diseases. The FAO has estimated that the need for pesticides in developing countries will increase by over 10% per year up to, and perhaps even beyond, 1985. Worsening pollution problems, however, have emphasized the need for a careful study of all foreign chemical residues which may find their way into food or the environment. The developed nations — the main market for the agricultural produce of the Third World — are also introducing increasingly stringent limits on the concentration of pesticide residues in food.

Labelling pesticides with radioactive or stable isotopes is a well-established technique for tracing the movement of chemical residues through food chains to the consumer. The Joint FAO/IAEA Division has initiated a programme of co-ordinated research into the fate of pesticides, using radioactive tagging techniques. In addition, the Division is encouraging the use of activation analysis to determine the concentration of industrial pollutants such as mercury, arsenic, manganese and bromine.

## THE GREEN REVOLUTION REQUIRES FERTILIZERS

The shorter stature of the new high-yielding varieties enables them to respond to high levels of fertilizer (especially nitrogen) by producing more grain. On the other hand, traditional varieties subjected to the same fertilizer treatment show little or no yield response and grow tall and spindly so that they tend to fall over (to "lodge") in rain or wind, bending the head of grain down to the ground where it is spoiled or lost.

The introduction of the new high-yielding varieties in developing countries has caused a new demand by farmers for fertilizers. The purchase of fertilizer may represent the farmers' only cash outlay for a crop, and is usually a strain on the hard currency resources of the developing countries. It is therefore necessary to insure that fertilizer is applied efficiently and with minimum loss.

A minute quantity of radioactive phosphorus or heavy nitrogen mixed with the fertilizer can be distinguished from the phosphorus or nitrogen already present in the soil or in the plant tissue. Thus the movement of fertilizer can be determined together with the amount of it taken up by the plant. The most efficient way of applying fertilizers can be determined from such measurements.

Radiation-sterilized insects may be released in the field from aircraft or, more simply, by ripping open the paper bags in which they are allowed to mature. Photo: FAO.

Fertilizers labelled with the isotope nitrogen-15 are used to measure the effectiveness of different fertiliz

nd cultural practices, as in this study in the Philippines. Photo: IAEA

Studies on fertilizer application must be carried out under field conditions in the developing countries by local agricultural scientists who are familiar with local crop-growing conditions. Crop cultural practices developed in the temperate zone, which has moderate rainfall, cannot be transferred without modification to a tropical zone with wet and dry seasons.

The first co-ordinated programme undertaken by the Joint FAO/IAEA Division was concerned with determining the best method of applying fertilizers to rice. By the early 1960's, when this co-ordinated rice fertilization programme was set up, phosphorus-32 was already well established as a tracer in fertilizer research for other crops. Nevertheless, much was still unknown about the best way to use phosphate fertilizers in the cultivation of rice. Where should the fertilizer be placed? When should it be applied? In what chemical form? Basically, the research involved the application of fertilizers labelled with phosphorus-32 at various places in the soil, at various times and in various chemical forms. This was followed by determination of the fraction of radioactive phosphorus taken up by the plants. Analyses of plant material were first carried out at the IAEA Laboratory at Seibersdorf near Vienna, but, as the research contractors became more experienced, they gradually took over this task. The rice experiments showed that phosphorus fertilizers are best placed on, or near, the soil surface. Other common practices, such as phoughing in fertilizers or applying them to the zone around the plant roots, result in less fertilizer phosphorus being absorbed by the plants.

The co-ordinated rice fertilization programme also included studies on nitrogen fertilizers, with nitrogen-15 as the labelling isotope. Experimental results showed that fertilizer nitrogen was lost to the atmosphere unless it is in the form of ammonium salts and is applied to the paddy soil below surface. The use of nitrogen-15 during these trials represented the first field application of this isotope on a large scale, reversing the usual pattern of events in which an advanced technology is first tested in technically advanced countries.

In recent years, methods of rice cultivation have begun to change. The paddy fields are no longer flooded throughout the growing season, but are drained and re-flooded. This practice can be expected to have a marked effect upon the way nitrogen fertilizers are utilized. The IAEA/FAO have therefore initiated co-ordinated research to ascertain how fertilizer practices should be modified or adapted to the new methods of cultivation. Similar co-ordinated research programmes are under way to improve fertilizer practice with maize and winter wheat.

Too much fertilizer, however, is sometimes used, and in such cases excessive amounts can be washed from the soil into streams and lakes by groundwater or rain. Excessive amounts of fertilizer can upset the ecological

Use of nuclear techniques provides guidance in making the most efficient application of fertilizers. When fertilizer is used to excess and is washed into lakes or rivers, it may upset the ecological balance, e.g. causing death to fish. Photo: UNESCO

balance in the waters, which creates problems that may effect man (growth of algae, exhaustion of oxygen, death of fish, etc.). Isotopic studies may be used as a basis for the introduction of agricultural practices which minimize such environmental pollution.

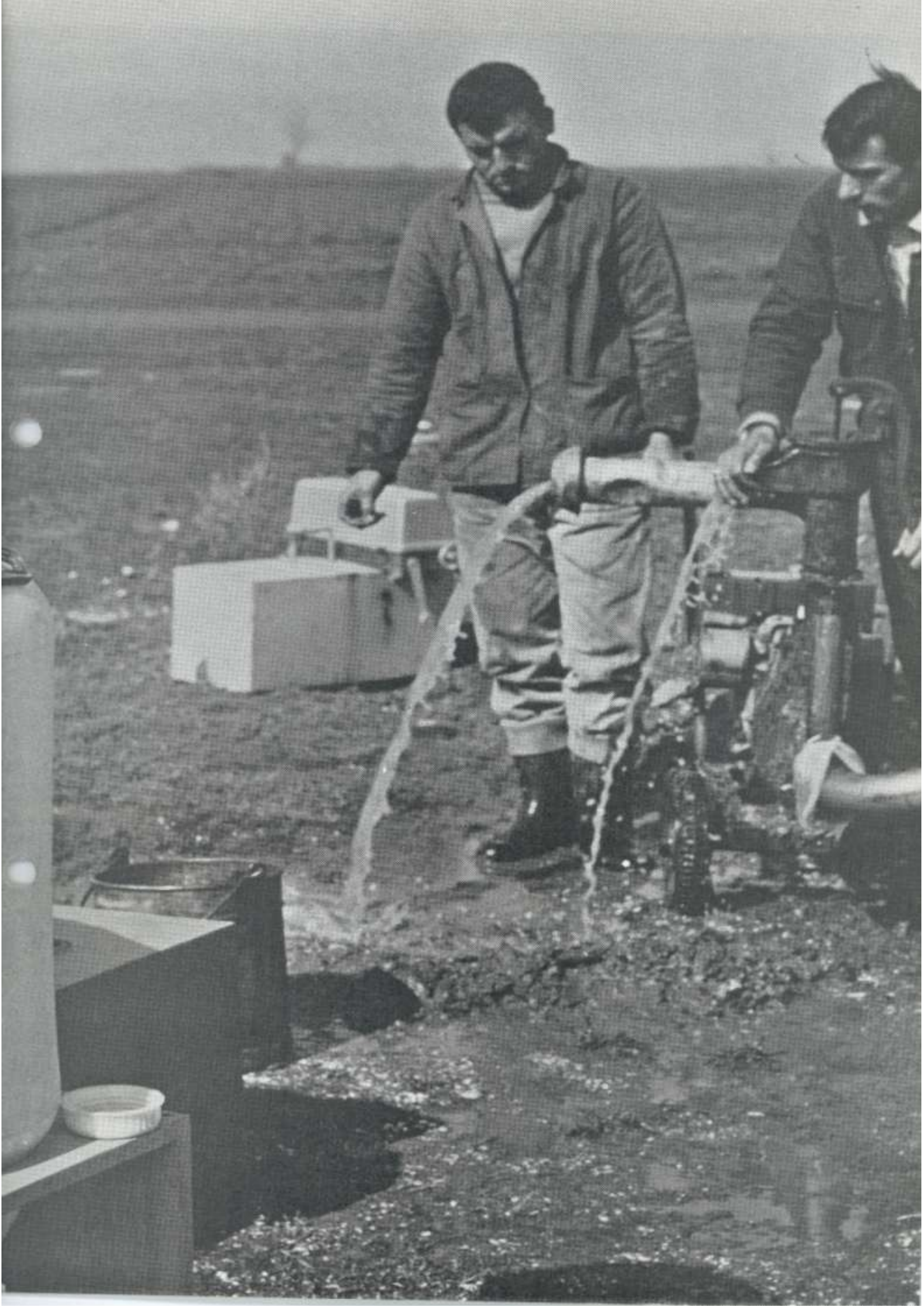
## THE GREEN REVOLUTION DEMANDS MORE WATER

To achieve their high crop yields, the new cereal varieties also need more water, in other words, irrigation or good soil moisture management. The introduction of expensive irrigation systems is thus a burden on the economic resources of developing countries, and efficient application of irrigation water is therefore essential. Since isotopes can be used to trace water movement at the soil surface and in natural underground reservoirs, their application in water management can reduce water losses.

In future, nuclear technology may contribute substantially to the supply of fresh water in some arid lands through nuclear-powered desalination plants. At present, nuclear techniques are being applied to planning the better use of water already available in the soil or underground. Natural underground reservoirs are now among the main sources of water for irrigation in semi-arid countries and this supply should be carefully husbanded. Rain which fell during the testing of thermonuclear devices from 1954 onwards became labelled with tritium (a radioactive isotope of hydrogen). This has enabled hydrologists to trace this "new" water and to distinguish it from "old" water deep underground and therefore to predict the rate at which water can be drawn off from these reservoirs without exhausting them. On a much smaller scale, tritium is utilized to study the behaviour of water near the soil surface. There is little doubt that in normal agricultural practices much of the water supplied by irrigation is lost through surface run-off or percolation below the zone of active root growth before it can be used by the crop.

Another nuclear technique used to determine the amount of water in the soil is based on the neutron moisture meter, which incorporates a radioactive source emitting neutrons. This technique is extremely important for scientific irrigation practice to improve the efficiency of water use. The Joint FAO/IAEA Division runs a co-ordinated research programme in developing countries which relies on this instrument.

Sampling water for isotopic age determination in the Thessaly Valley, Greece. Photo: E. Bradley




Nuclear radiation is helping scientists to improve existing food plants. In the photo is a radiation-indu
shown on the right, has shorter stem, resists bad weather and makes better use of fertilizer. Photo: T. Kawai

# NUCLEAR TECHNIQUES CAN EXTEND THE GREEN REVOLUTION

As cereal yields in the developing countries rise, less land will be required to grow the same amount of grain. It should then become possible to use the "spare" land for raising animals or for other crops, such as fruits, vegetables, cotton and other industrial crops. Radiation breeding has been used to improve such plants in many ways, especially to shorten the growing period. As in the case of grains, other nuclear techniques can be used to combat insects and plant disease and to economize on fertilizer and water. If the land is used for grazing animals, many problems of nutrition and disease can be solved with the aid of nuclear techniques. Isotopic tracers are routinely employed in studying animal nutrition. Radiation offers a unique method of producing vaccines to protect livestock against certain particularly destruc-


mutant variety of soybean (left) grown by Japanese farmers. It matures 25 days earlier than the mother variety

tive parasites. There is hope that other animal pests, such as the tsetse fly, may also be controlled through insect sterilization. The Joint Division conducts co-ordinated programmes on the above nuclear applications.

Harvested crops must be safely stored. Radiation techniques to destroy beetles and insects in stored grain are currently being studied. The techniques for preserving fruits and vegetables by pasteurizing doses of radiation are already well developed, but, to be used commercially, this process must be economically competitive and the remaining licensing difficulties must be overcome. These questions are also being dealt with by the Joint Division.

The Green Revolution makes a great many demands on agricultural technology and research, as the foregoing account makes clear. With the wider application of modern agricultural technology and of agricultural research in developing countries, nuclear and other advanced techniques will make an ever-increasing contribution to the Green Revolution.

# ANNEX

# ACTIVITIES OF THE IAEA AND FAO IN FOOD AND AGRICULTURE

At the time of writing, the FAO and the IAEA are carrying out twenty-one co-ordinated research programmes in food and agriculture, involving over 200 research groups mainly in developing countries (see List I). In awarding a research contract, the primary consideration is the ability of the contractor to do the work required. Over the years, more and more laboratories in the developing countries have proved capable of meeting this requirement.

The amount of money granted for an individual research contract is very small, usually only two to four thousand dollars per year. In 1970, the two international agencies provided a total of US $267 000 for such contracts in food and agriculture. The bulk of the funds for research, however, is provided by the national institute itself, which thus has a major stake in the project. A research contract is a contractual agreement by which the institute undertakes to perform specific research that will benefit most or all of the Member States of FAO and the IAEA. In many cases, the experts, fellowships and equipment given through the technical assistance programmes of the two agencies may have enabled a country to train its scientists and to build and equip laboratories. Subsequently, a research contract helps to launch a research programme utilizing such scientific staff and laboratories.

A special form of research contract, termed "research agreement", does not provide for financial support to an institute, but involves the agencies in the expense of scientists' participation in programme co-ordination meetings. These agreements (marked with an asterisk in List I) are most commonly concluded with institutes in the technically advanced countries, and enable the agencies to tap the scientific resources of such institutes for international collaboration in solving problems of special importance to the developing countries.

Scientific research thrives on the interaction of people and ideas. Frequently, however, scientists in developing countries are deprived of an opportunity to meet fellow experts. In the co-ordinated research programmes, meetings of all the chief scientific investigators from the participating institutes are held periodically to review progress, discuss common problems, and decide on future action. The cost of such meetings is borne by FAO and the IAEA.

Besides co-ordinating research programmes, the Joint Division arranges symposia and other scientific meetings (see List II), gives advice to Member States, prepares technical publications (see List III) and helps to supervise

At the Indian Agricultural Research Institute, New Delhi, a new laboratory building for nuclear research in agriculture is being built, funded by the UNDP and the Indian Government. Photo: IARI.

fellowship training, and to organize international training courses (see List IV). In 1970, 22.7% of all the technical assistance given by the IAEA was related to the application of nuclear techniques in food and agriculture and amounted to US $820 000.

Finally, the Joint Division provides technical supervision for projects supported by the UNDP Special Fund: (1) Nuclear Research and Training in Agriculture (Yugoslavia); (2) The Eradication of the Mediterranean Fruit Fly (Regional Project for Central America); and (3) Nuclear Research in Agriculture (India).

The Joint Division also provides supporting laboratory services for nuclear techniques in food and agriculture. The IAEA Laboratory at Seibersdorf, about 35 kilometres south of Vienna, has the only agricultural research facility directly under the control of a United Nations organization. Its programme is the responsibility of both FAO and the IAEA. The main functions of the Laboratory's agricultural group are: contributing research support to the co-ordinated programmes; providing such services to Member States as irradiation treatments, isotopic analyses and preparation of standards; and training scientists from developing countries in both laboratory and field techniques.

## LIST I Complete List of Co-ordinated Research Programmes by January 1971

1. *Rice Fertilization* (*1962—1968*)
   Burma, Ceylon, China (2), Hungary, India, Italy, Korea, Madagascar, Pakistan (2), Philippines, Thailand, United Arab Republic.

2. *Maize Fertilization* (*1964—1968*)
   Argentina, Brazil, Colombia, Ghana, Mexico, Peru, Romania, United Arab Republic.

3. *Water use efficiency* (*1965*)
   Belgium, Brazil, Germany, Federal Republic of*, Iran, Iraq, Israel, Kenya, Lebanon, Morocco, Pakistan, Sudan, United Arab Republic.

4. *Wheat Fertilization* (*1967*)
   Brazil, Greece, Hungary, India*, Italy*, Lebanon, Mexico, Morocco, Pakistan, Peru, Romania, Turkey, United Arab Republic.

5. *Use of fertilizers in tree cultures* (*1967*)
   Ceylon, China, Colombia, Ghana, Ivory Coast*, Japan*, Kenya, Malaysia*, Philippines, Spain, Tunisia, Uganda.

6. *Physico-chemical relationships of soils and plants* (1966)
Australia, Belgium, Burma, Canada*, Denmark*, Ghana, Hungary (1), (1)*, India, Japan, Madagascar, Netherlands*, Pakistan (2), Poland, United States of America.

7. *Rice Fertilization and irrigation* (1969)
Indonesia, Pakistan, Sudan, Thailand.

8. *Use of induced mutations for rice improvement* (1964)
Brazil, Ceylon, China, India, Japan*, Korea, Pakistan (2), Philippines, Thailand, Viet-Nam.

9. *Use of induced mutations in plant breeding* (1966)
Argentina, Australia, Denmark*, France*, Germany, Federal Republic of*, India*, Italy (2)*, Japan*, Sweden (2)*, USSR*, United States of America (3)*, Yugoslavia*.

10. *Use of neutrons in seed irradiation* (1966)
Austria*, Bulgaria, China, France*, Germany, Federal Republic of*, India, Italy*, Netherlands*, Philippines, Puerto Rico*, Thailand, United Kingdom*, United States of America (3)*, Venezuela.

11. *Use of nuclear techniques for seed protein improvement* (1968)
China, India, Japan, Korea, Pakistan, Philippines, Thailand.

12. *Etiology, effects and control of parasitic diseases in domestic animals* (1967)
ČSSR*, Denmark*, Hungary, Israel*, Italy*, Kenya (2), United Kingdom*, United States of America*, Yugoslavia*.

13. *Trace element metabolism and disease in animals of agricultural importance* (1968)
Argentina, Austria*, Cuba, Denmark*, Germany, Federal Republic of (2)*, Netherlands*, United Kingdom (2)*, United States of America (3)*, Yugoslavia*.

14. *Control of animal insect pests by the sterile male technique* (1967)
Belgium*, El Salvador, France*, Germany, Federal Republic of*, Kenya, Portugal, United Kingdom*, Venezuela*.

15. *Rice insect control and eradication* (1968)
China (2), Japan, Korea, Pakistan (2), Thailand (2).

16. *Fruit fly eradication or control by the sterile male technique* (1967)
Austria*, Germany, Federal Republic of*, Netherlands, Portugal, Spain (2), (2)*, Switzerland*.

17. *Ecology and behaviour of the Heliothis complex as related to the sterile male technique* (1969)
Argentina, El Salvador, Mexico, United States of America*.

18. *Microbiological aspects of food preservation by irradiation* (1965)
Australia*, Germany, Federal Republic of*, Hungary*, Japan*, Netherlands, Sweden, Thailand, United States of America*.

19. *Tissue physiology in food preservation by irradiation* (1966)
Denmark*, Germany, Federal Republic of (1), (1)*, Hungary, Iraq, Israel, Italy*, Japan, Pakistan.

20. *Preservation of fishery products by irradiation* (1969)
Belgium, Germany, Federal Republic of, Iceland, Korea, Philippines, Spain (2), Thailand.

21. *The shelf-life extension of fruit and vegetables* (1970)
Germany, Federal Republic of, Hungary, Iraq, Philippines.

---

* "cost-free" research agreement.

## LIST II Symposia and Seminars arranged by the Joint FAO/IAEA Division*

1. FAO/IAEA Symposium on the Use of Radioisotopes in Animal Nutrition and Physiology, 23—27 November 1964, Praque, ČSSR.

2. FAO/IAEA Symposium on the Use of Isotopes and Radiation in Soil-Plant Nutrition Studies, 28 June—2 July 1965, Ankara, Turkey.

3. FAO/IAEA Symposium on the Use of Isotopes in Weed Research, 25—29 October 1965, Vienna, Austria.

4. FAO/IAEA Symposium on Food Irradiation, 6—10 June 1966, Karlsruhe, Germany, Federal Republic of.

5. FAO/IAEA Seminar on the Use of Radioisotopes and Radiation in Dairy Science and Technology, 12—15 July 1966, Vienna, Austria.

6. FAO/IAEA Symposium on the Use of Isotopes in Plant Nutrition and Physiology Studies, 5—9 September 1966, Vienna, Austria.

7. FAO/IAEA Symposium on the Use of Isotopes and Radiation in Soil Physics and Irrigation Studies, 12—16 June 1967, Istanbul, Turkey.

8. FAO/IAEA Symposium on the Use of Isotopes in Studies of Nitrogen Metabolism in the Soil-Plant-Animal System, 28 August — 1 September 1967, Vienna, Austria.

9. FAO/IAEA Symposium on the Use of Radiation and Isotopes in Entomology, 4—8 December 1967, Vienna, Austria.

10. FAO/IAEA Symposium on the Use of Isotopes and Radiation in Soil-Organic Matter Studies, 15—19 July 1968, Vienna, Austria.

11. FAO/IAEA/WHO Seminar on Agricultural and Public Health Aspects of Environmental Contamination by Radioactive Materials, 24—28 March 1969, Vienna, Austria.

12. FAO/IAEA Symposium on Nature, Induction and Utilization of Mutations in Plants, 14—18 July 1969, Pullman, Washington, United States of America.

13. FAO/IAEA Symposium on Plant Protein Resources: Their Improvement through the Application of Nuclear Techniques, 8—12 June 1970, Vienna, Austria.

14. FAO/IAEA Symposium on the Sterility Principle for Insect Control or Eradication, 14—18 September 1970, Athens, Greece.

* In addition, panel meetings of experts, research coordination meetings and an occasional study group are held as required by the programmes of the various sections of the Division.

## LIST III Publications prepared by the Joint FAO/IAEA Division

1. Laboratory Training Manual on the Use of Isotopes and Radiation in Soil-Plant Relations Research (STI/DOC/10/29), Technical Reports Series No. 29, IAEA, Vienna (1964).

2. Production and Urilization of Radiation Vaccines Against Helminthic Diseases (STI/DOC/10/30), Technical Reports Series No. 30, IAEA, Vienna (1964).

3. The Use of Induced Mutations in Plant Breeding, Pergamon Press (1965).

4. Radioisotopes in Animal Nutrition and Physiology, (Proc. Symp. Praque, 1964) (STI/PUB/90), IAEA, Vienna (1965).

5. The Technical Basis for Legislation on Irradiated Food, FAO Atomic Energy Series No. 6, (1965).

6. Advances in Insect Population Control by the Sterile-Male Technique (STI/DOC/10/44), Technical Reports Series No. 44, IAEA, Vienna (1965).

7. Radioisotopes and Ionizing Radiations in Entomology (1961—1963) (STI/PUB/21/15), Bibliographical Series No. 15, IAEA, Vienna (1965).

8. Plant Nutrient Supply and Movement (STI/DOC/10/48), Technical Reports Series No. 48, IAEA, Vienna (1965).

9. Isotopes and Radiation in Soil-Plant Nutrition Studies (Proc. Symp. Ankara, 1965) (STI/PUB/108), IAEA, Vienna (1965).

10. The Use of Isotopes in Soil Organic Matter Studies, Pergamon Press, (1966).

11. Isotopes in Weed Research (Proc. Symp. Vienna, 1965) (STI/PUB/ 113), IAEA, Vienna (1966).

12. Applications of Food Irradiation in Developing Countries (STI/DOC/ 10/54) Technical Reports Series No. 54, IAEA, Vienna (1966).

13. Laboratory Training Manual on the Use of Isotopes and Radiation in Entomology (STI/DOC/10/61), Technical Reports Series No. 61, IAEA, Vienna, (1966).

14. Effects of Low Doses of Radiation on Crop Plants (STI/DOC/10/64), Technical Reports Series No. 64, IAEA, Vienna (1966).

15. Limiting Steps in Ion Uptake by Plants from Soil (STI/DOC/10/65), Technical Reports Series No. 65, IAEA, Vienna (1966).

16. Isotopes and Radiation in Plant Pathology (STI/DOC/10/66), Technical Reports Series No. 66, IAEA, Vienna (1966).

17. Radioisotopes in the Detection of Pesticide Residues (Proc. Panel Vienna, 1965) (STI/PUB/123), IAEA, Vienna (1966).

18. Food Irradiation (Proc. Symp. Karlsruhe, 1966) (STI/PUB/127), IAEA, Vienna, (1966).

19. Radioisotopes and Radiation in Dairy Science and Technology (Proc. Symp. Vienna, 1966) (STI/PUB/135), IAEA, Vienna (1966).

20. Mutations in Plant Breeding (Proc. Panel. Vienna, 1966) (STI/PUB/129), IAEA, Vienna (1966).

21. Soil-Moisture and Irrigation Studies (Proc. Panel Vienna, 1966) (STI/PUB/133), IAEA, Vienna (1967).

22. Isotopes in Plant Nutrition and Physiology (Proc. Symp. Vienna, 1966), (STI/PUB/137), IAEA, Vienna, (1967).

23. Radioisotopes and Ionizing Radiations in Entomology (1964—1965) (STI/PUB/21/24), Bibliographical Series No. 24, IAEA, Vienna (1967).

24. Neutron Irradiation of Seeds (STI/DOC/10/76) Technical Reports Series No. 76, IAEA, Vienna, (1967).

25. Isotope and Radiation Techniques in Soil Physics and Irrigation Studies (Proc. Symp. Istanbul, 1967) (STI/PUB/158), IAEA, Vienna (1967).

26. Microbiological Problems in Food Preservation by Irradiation (Proc. Panel. Vienna, 1966) (STI/PUB/168), IAEA, Vienna (1967).

27. Preservation of Fruit and Vegetables by Radiation (Proc. Panel, Vienna, 1966) (STI/PUB/149), IAEA, Vienna (1968).

28. Isotope Studies on the Nitrogen Chain (Proc. Symp. Vienna, 1967) (STI/PUB/161), IAEA, Vienna (1968).

29. Isotopes and Radiation in Entomology (Proc. Symp. Vienna, 1967) (STI/PUB/166), IAEA, Vienna (1968).

30. Isotopes and Radiation in Parasitology (Proc. Panel Vienna, 1967) (STI/PUB/181), IAEA, Vienna (1968).

31. Mutations in Plant Breeding II (Proc. Panel. Vienna, 1967) (STI/PUB/182), IAEA, Vienna (1968).

32. Rice Breeding with Induced Mutations (STI/DOC/10/86), Technical Reports Series No. 86, IAEA, Vienna (1968).

33. Radiation, Radioisotopes and Rearing Methods in the Control of Insect Pests (Proc. Panel Tel Aviv, 1966) (STI/PUB/185), IAEA, Vienna (1968).

34. Control of Livestock Insect Pests by the Sterile-Male Technique (Proc. Panel Vienna, 1967) (STI/PUB/184), IAEA, Vienna (1968).

35. Elimination of Harmful Organisms from Food and Feed by Irradiation (Proc. Panel Zeist. 1967) (STI/PUB/200), IAEA, Vienna (1968).

36. Neutron Irradiation of Seeds II (Proc. Panel Vienna, 1967) (STI/DOC/10/92), IAEA, Vienna (1968).

37. Isotopes and Radiation in Soil Organic-Matter Studies (Proc. Symp. Vienna, 1968) (STI/PUB/190), IAEA, Vienna (1968).

38. New Approaches to Breeding for Improved Plant Protein (Proc. Panel Röstånga, 1968) (STI/PUB/212), IAEA, Vienna (1969).

39. Laboratory Training Manual on the Use of Isotopes and Radiation in Animal Research - Second Edition (STI/DOC/10/60), Technical Reports Series No. 60, IAEA, Vienna (1969).

40. Nuclear Techniques for Increased Food Production, FAO Basic Study No. 22 (1969).

41. Trace Mineral Studies with Isotopes in Domestic Animals (Proc. Panel Vienna, 1968) (STI/PUB/218), IAEA, Vienna (1969).

42. Enzymological Aspects of Food Irradiation (Proc. Panel Vienna, 1968) (STI/PUB/216), IAEA, Vienna (1969).

43. Sterile-Male Technique for Eradication or Control of Harmful Insects (Proc. Panel Vienna, 1968) (STI/PUB/224), IAEA, Vienna (1969).

44. Environmental Contamination by Radioactive Materials (Proc. Sem. Vienna, 1969) (STI/PUB/226), IAEA, Vienna (1969).

45. Insect Ecology and the Sterile-Male Technique (Proc. Panel Vienna, 1967) (STI/PUB/223), IAEA, Vienna (1969).

46. Induced Mutations in Plants (Proc. Symp. Pullman, 1969) (STI/PUB/231), IAEA, Vienna (1969).

47. Isotopes and Radiation in Parasitology II (Proc. Panel Vienna, 1969) (STI/PUB/242), IAEA, Vienna (1970).

48. Nuclear Techniques for Studying Pesticide Residue Problems (Proc. Panel Vienna, 1968) (STI/PUB/252), IAEA, Vienna (1970).

49. Rice Fertilization (STI/DOC/10/108) Technical Reports Series No. 108, IAEA, Vienna (1970).

50. Microbiological Specifications and Testing Methods for Irradiated Food (STI/DOC/10/104) Technical Reports Series No. 104, IAEA, Vienna (1970).

51. Training Manual on Food Irradiation Technology and Techniques (STI/DOC/10/114) Technical Reports Series No. 114, IAEA, Vienna (1970).

52. Isotope Techniques for Studying Animal Protein Production from Non-Protein Nitrogen (STI/DOC/10/111) Technical Reports Series No. 111, IAEA, Vienna (1970).

53. Manual on Mutation Breeding (STI/DOC/10/119) Technical Reports Series No. 119, IAEA, Vienna (1970).

54. Rice Breeding with Induced Mutations II (STI/DOC/10/102) Technical Reports Series No. 102, IAEA, Vienna (1970).

55. Improving Plant Protein by Nuclear Techniques (Proc. Symp. Vienna, 1970) (STI/PUB/258), IAEA, Vienna (1970).

56. Wholesomeness of Irradiated Food with Special Reference to Wheat, Potatoes and Onions, WHO Technical Reports Series No. 451 (1970).

## LIST IV Training Courses organized by the Joint FAO/IAEA Division*

1. Regional Training Course on the Application of Radioactive Isotopes in Soil-Plant Relations, 22 September — 13 November 1964, São Paulo, Brazil.

2. Regional Training Course on Applications of Radioisotopes in Agriculture, 17 April — 12 June 1965, Cairo, United Arab Republic.

3. International Training Course on the Use of Radioisotopes and Radiation in Forestry Research, 11 May — 3 July 1965, Hannover, Germany, Federal Republic of.

4. International Training Course on Radioisotopes in Animal Science and Veterinary Medicine, 19 July — 11 September 1965, Cornell University, Ithaca, N.Y., United States of America.

5. International Training Course on the Application of Radioisotopes and Radiation in Entomology, 4 October — 26 November 1965, Gainesville, Fla., United States of America.

6. Regional Training Course on the Application of Radioactive Isotopes in Soil-Plant Relations, 11 October — 3 December 1965, Bogotá, Colombia.

7. FAO/IAEA/WHO Training Course on Surveys for Radionuclides in Food and Agriculture, 8 November — 17 December 1965, Vienna, Austria.

8. International Training Course on the Use of Radioisotopes in Soil and Plant Investigations, 3 October — 25 November 1966, Manila, Philippines.

9. International Training Course on Food Irradiation Technology, 19 June — 11 August 1967, Michigan State University, East Lansing, Mich., United States of America.

10. International Training Course on the Use of Radiation and Radioisotopes in Entomology, 2 October — 24 November 1967, Gainesville, Fla., United States of America.

11. International Training Course on the Use of Isotopes and Radiation in Animal Science and Veterinary Medicine, 2 October — 11 November 1967, Brno, ČSSR.

12. International Training Course on the Use of Radiation and Isotope Techniques in Horticultural Research, 22 July — 13 September 1968, Hannover, Germany, Federal Republic of.

13. International Training Course on the Use of Radiation and other Mutagen Treatments for Crop Improvement, 12 May — 20 June 1969, Casaccia, Italy.

14. International Advanced Training Course on Food Irradiation Technology and Techniques, 16 June — 25 July 1969, Boston, Mass., United States of America.

15. International Training Course on the Use of Isotopes and Radiation in Entomology, 6 October — 28 November 1969, Gainesville, Fla., United States of America.

16. Inter-regional Training Course on the Use of Isotopes and Radiation Equipment in Soil and Plant Nutrition Studies, 3 November — 19 December 1969, Teheran, Iran.

17. Regional Training Course on the Use of Isotopes and Radiation in Entomology, 20 April — 29 May 1970, Turrialba, Costa Rica.

18. Inter-regional Training Course on the Use of Radioisotopes and Radiation in Animal Science and Veterinary Medicine, 4 May — 12 June 1970, Zemun, Yugoslavia.

19. International Training Course on the Use of Isotopes and Radiation in Soil-Plant Nutrition Studies, 8 June — 24 July 1970, Wageningen, Netherlands.

20. International Training Course on the Use of Radioisotopes and Radiation in Animal Science and Veterinary Medicine, 20 July — 4 September 1970, Cornell University, Ithaca, N.Y., United States of America.

---

* Each of these courses normally involves 15—25 trainees.


FAO
FIAT PANIS