

This is No. 4 in the series: What Can Radioisotopes Do for Man?

Food and Environmental Quality Protection

by F.P.W. Winteringham*

Radioisotopes can surely do nothing for man.
Alternative answers can be envisaged to the question –
What can man do with radioisotopes?
Destroy or help himself.
The explosive advance of applied science since Hiroshima,
the evident nature of man and contemporary society
(cf. works of Robert Ardrey, Jacob Bronowski and the Club of Rome),
and modest extrapolation into the future
do not, unhappily,
suggest a negligible probability of the first alternative.
In her statement to a plenary session
of the Triennial Conference of the International Council of Women
(Conseil international des femmes, Paris, PLE/73/24)
held in 1973 my late wife said:
“I welcome this opportunity of brief comment
in relation to the International Atomic Energy Agency
of the United Nations family ...
created to promote the peaceful uses of atomic energy.
Let us never forget the appalling alternatives ...
Under no circumstances
should we, as women,
ignore these issues because of their apparently technical background.
Science and technology today, selfishly applied,
could spoil the environment and its resources
for generations to come”.

It is International Women's Year
and this contribution is dedicated to the memory of my wife.
It relates to the peaceful uses of isotopes in food
and environmental quality protection and complements
the second to the series
by Dr. Ralph M. Kniseley
relating to medical and biological applications.



* Head, Chemical Residues and Pollution Section, Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture

BACKGROUND

Trace man-made chemical contaminants do represent a sinister threat to environmental quality (and, therefore, that of dependent living organisms and their food). Sinister, in the sense that they can usually only be detected and identified by the sophisticated techniques of modern science and the effects may be slow to develop; but the biological consequences can be none the less serious. The tragedy of Minamata and the world-wide problems of eutrophication stand witness. Moreover, the mechanisms involved "are very complex and not easily understood by the layman. Therefore, the scientist has a special responsibility to study their nature, magnitude and biological significance, and to present his conclusions impartially." (FAO/IAEA Expert Panel, Vienna, 1970).

The use of radioactive or stable isotopes as tracers of atoms or molecules in food, environment or in living organisms probably represents the biggest development in biological research technique since the application of the microscope by Leeuwenhoek in the 17th century.

The use of radioactive tracers is not new. As early as 1923 Hevesy studied the absorption of lead by plants using the naturally occurring isotope of lead – thorium B. However, it was not until the construction of nuclear reactors, first in Chicago in 1942, that artificial radioactive isotopes became available in sufficient quantities for their widespread use as trace

Radiotracer techniques are now well established as a powerful research tool. In combination with chromatographic and other fractionation techniques they are widely used for basic studies of the behaviour, fate and significance of residues of pesticides (e.g. insecticides, fungicides, herbicides), drugs, detergents, industrial chemicals and wastes, etc. which find their way as trace contaminants into food, environment and living organisms. "The fields of intermediary metabolism and detoxication mechanisms were largely rewritten after the advent of radiotracer approaches ... Radiotracer studies on metabolism and fate of pesticides are no longer just a means of satisfying academic curiosity on compounds which are already in use; on the contrary, they are now generally a necessary and critical step in understanding the persistence and action of a pesticide before it enters actual use." (Casida, 1969).

The use of stable isotopes as tracers, as distinct from the knowledge of their existence, was effectively made possible by H.C. Urey in 1931 by his successful concentration of deuterium (^2H), and used as a tracer, also by Hevesy, soon afterwards.

Given a novel and powerful research tool it is tempting to build a programme on problems which fit the tool. The value of this approach is debatable. There is, however, no doubt that isotope techniques *coupled with their almost invariably associated facilities* (high standards of laboratory design and safety, instrument maintenance, expertise, etc.) have made a major contribution to our understanding of the behaviour and significance of chemical and radioactive contaminants and indeed of the capacities of environmental ecosystems themselves to receive such contaminants without unacceptable effects. Moreover, it might be argued cogently that such understanding deserves higher priority than at present if the really critical situations or pathways are to be identified and "monitoring" programmes developed more rationally. For example, adequate research data on the behaviour and biological significance of a pesticide and its residues under the range of conditions for effective pest control will clearly indicate the limits for its safe usage. If by education and controls at the time of application these limits were observed then might

not the need for some bureaucratic machinery and monitoring programmes be obviated? This approach is, in fact, effectively applied in pharmacology and medicine. Once the limits for the safe and effective use of a new drug have been established it is widely used without recourse to taking samples of the patient's tissues or excreta as part of some monitoring programme to determine its residues.

ISOTOPIC TECHNIQUES FOR "TRACING" OR "MONITORING"

It is convenient to consider two kinds of application: (1) "Tracer" studies in which a contaminant or pollutant labelled with stable or radioactive isotopes is added to the system in order to study its behaviour, chemical and physical fate under experimental or simulated conditions of practice. (2) As a "monitoring" tool for studying an existing contamination or exposure situation.

The first kind of application includes the conventional use of isotopes as tracers and is usually a research application in the sense that the system being studied, whether food, an environmental medium such as soil or water, or a living animal or plant organism is artificially exposed to the contaminant or pollutant for the purpose of the investigation.

The second kind of application includes the well-established techniques of radioactivation and isotope dilution analysis. It also includes the less well-known techniques of using labelled substrates or reagents for monitoring or investigating existing systems already contaminated or exposed. The latter are the environmental equivalents to the use of radioisotopes as a diagnostic tool and for radio-immuno assay in modern medicine (see IAEA BULLETIN, Vol. 16, No. 5, the second article of this series). In the context of environmental quality protection their potential appears to have been relatively unexploited. Both kinds of application to food and environmental quality research and protection have been the subject of IAEA publications (listed in the appended bibliography).

RADIOACTIVE TRACER STUDIES

A wide range of potential contaminants or pollutants labelled with radioactive hydrogen (tritium-³H), – carbon (¹⁴C), – sulphur (³⁵S), – phosphorus (³²P), – iodine (¹³¹I), – or other radioactive isotopes are now commercially available at specific radioactivities of 10 or more millicuries per gram. These include drugs, pesticides, industrial solvents, fertilizers, food additives, organic intermediates, etc. Moreover, methods for preparing any of the almost entire range of synthetic organic chemicals for agriculture, medicine and industry from simple commercially available labelled intermediates are described in the scientific literature. Many of the major manufacturers of new agro-chemicals and pharmaceuticals routinely prepare their products in labelled form to determine the safe limits for their marketing and use (see Fig. 2). Similarly, radioactive isotopes of many "toxic" elements are commercially available such as radioactive arsenic (⁷⁶As), – cadmium (^{115m}Cd), – chromium (⁵¹Cr), – lead (as radium D), mercury (²⁰³Hg), – selenium (⁷⁵Se), – zinc (⁶⁵Zn), etc.

This means that the behaviour, persistence and fate of such contaminants in soil, water, food, plant or animal tissues can be studied experimentally at concentrations less than 1 part in 10⁹. Such concentrations of pesticide residues in food, for example, are very much lower than those considered by WHO to be of any toxicological significance to man during a lifetime of exposure. Moreover, by radio-cochromatographic or other fractionation techniques with known substances, the identity of the degradation or reaction products of



Figure 2: What is the ultimate fate of insecticide sprayed for fruit pest? Isotope techniques play a vital role in answering such questions and in establishing safe conditions for pesticide usage.

the contaminant can often be established unequivocally at concentrations of the contaminant well below those which would enable them to be detected by conventional chemical analysis.

The common principle in studies of persistence and fate is first to prepare the pesticide, drug or potential contaminant or pollutant in suitably labelled form. It is then applied under experimental or simulated conditions of expected exposure or contamination. After different times samples are collected (e.g. of animal excreta, blood, plant tissues or processed food, soil, water, etc.), assayed for total radioactivity, extracted and fractionated and the radioactivities of the fractions also assayed. The proportion of radioactivity accounted for, and the fraction in which it occurs, quantify, characterize and sometimes identify it chemically, even though it may be a degradation product totally dissimilar to the original substance. In this way it was, for example, possible to study the fate of a DDT residue in wheat from the time of application as an insecticide through all the processes of flour milling, bread baking and final consumption by experimental animals (including the author!). Fractionation of the radioactive DDT derivatives recovered at various stages and their assay by radiochromatogram scanning (see Fig. 1) made it possible to follow its fate as far as "terminal" excretion as a polar non-toxic metabolite in the urine of man. There is now an immense literature based on such applications which describe the persistence and ultimate fate of a large range of "foreign" chemical residues which find their way into food, environment and living tissues (cf. Fig. 2).

Two important aspects have been illustrated by the Joint FAO/IAEA co-ordinated research programmes implemented to help scientists of the "Third World" to identify and study their own problems under their own conditions. Firstly, contamination and pollution problems are often just as serious in "developing" countries but more neglected

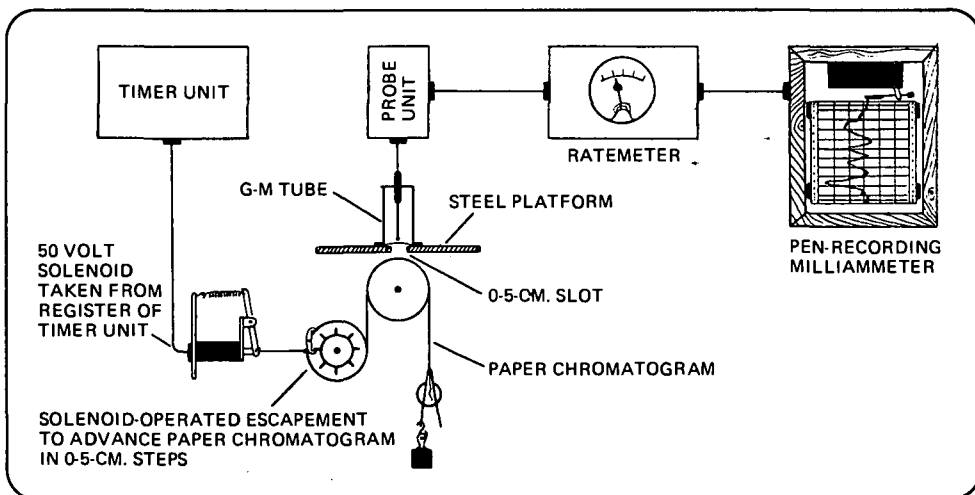


Figure 1: A radio paper chromatogram scanner developed by the author more than 25 years ago for studying the fate of trace contaminants in food and living tissues. Such combined radioactive tracer-chromatographic techniques are now extensively used in laboratories for studying the fate and persistence of drugs, pesticides, detergents and other potential contaminants or pollutants.

than in advanced countries. For example, where rapid industrialization has overtaken traditional fisheries around river estuaries but where the sophisticated research and legislation, taken for granted in advanced countries, are lacking. The second aspect is that the nature of the problems may be quite different under the conditions of a “developing” country so that existing published data are not always applicable or available. For example in the use of insecticides and fungicides for cocoa protection in West Africa.

A unique property of the isotope tracer technique, in addition to its extreme sensitivity and specificity for the labelled substance, is that the labelled material has, for all practical purposes, properties identical with the normal or unlabelled chemical compound or element, yet can be detected and assayed by its emitted radiation. Thus, the behaviour of labelled DDT can be studied in the presence of existing detectable contamination which, in the case of DDT, applies to the entire biosphere.

Another advantage is that in many cases, the presence of the labelled compound can be estimated and its distribution determined by non-destructive techniques. Thus, “bio-accumulation” by fish *in vivo* and concentration in a particular organ of a labelled aquatic contaminant can be followed by “whole body” remote counting or scanning techniques. The distribution of a labelled systemic fungicide in entire plants, or in histological sections, can be photographed as “autoradiographs”, prepared simply by placing a photographic plate or emulsion in contact with the sample in the dark for the necessary time. Indeed, it was through the effects of radioactivity (from a uranium salt) on a photographic emulsion in the dark that radioactivity was discovered by Henri Becquerel in 1896.

Isotope techniques, like all others, have their pitfalls and limitations. The pitfalls are usually due to ignorance of nuclear properties or of the biochemistry of the system being studied. Limitations are mainly due to relatively high costs of preparing many labelled compounds, real or imaginary radiation hazards, and the fact that many otherwise useful

radioactive isotopes have too short "half-lives". E.g., radioactive bromine-82 loses half its radioactivity every 35 hours. The duration of experiments with such isotopes has usually to be limited to 10 to 15 half-lives. These times are much too short for studying many environmental problems.

It is for these reasons especially that training courses in the use of isotope techniques for studying food and environmental contamination problems are important. While unique and powerful tools they cannot be safely and effectively picked up and used like a microscope.

STABLE ISOTOPIC TRACERS

The limitations of radioactive tracers due to radioactive decay (short half-lives of some isotopes, and possible radiation hazards) usually preclude large-scale experiments under field conditions. Moreover, suitable radioactive isotopes of at least two important elements in this context — nitrogen and oxygen — do not exist.

The FAO/IAEA Symposium held in Vienna in November 1974 (Isotope Ratios as Pollutant Source and Behaviour Indicators, IAEA Symposium Proceedings, Vienna, 1975, STI/PUB/382) demonstrated some dramatic improvements in the availability and use of stable isotopes as tracers. These stem from the more efficient and economic separation of stable isotopes, notably ^{12}C , ^{13}C , ^{14}N , ^{15}N , ^{16}O , ^{17}O , ^{18}O and ^{34}S , increased sensitivity and availability of instruments for their measurement, and the widening range of available stable-isotopically labelled chemical compounds. Elements and their compounds, labelled by altering the ratio of the isotopes naturally present (e.g., by ^{14}N depletion or ^{15}N enrichment of the natural nitrogen), are now actually available in kilogram quantities. These materials can be used under field conditions with no risk of radiation hazard and with no time limit due to radioactive decay. Advances in instrumentation and methodology have also placed their use within the reach of the smaller Institute budget; adequate stable isotope assay equipment can now be obtained for under US \$50 000.

With the use of modern mass spectrometers and nuclear magnetic resonance (NMR), spectroscopy enables not only the isotope ratio to be measured but also indicates location of the isotope and molecular structure. The use of "multiple-labelling" techniques makes it possible to detect labelled molecules under conditions of environmental dilution which can rival those of a single radioisotopic label. Thus, the probability, under its normal condition of synthesis, of the formation of the herbicide 2,4,5-T uniformly labelled with ^{13}C is less than 1 part in 10^{15} . The use of the herbicide so artificially labelled would, therefore, enable it to be detected unequivocally after enormous dilution.

There is clearly great potential for the use of stable isotopic tracers in environmental research. In this context the Joint FAO/IAEA/GSF co-ordinated research programme on agricultural nitrogen residues might be noted. It was recently greatly expanded through the generosity of the Federal Republic of Germany and is based on co-ordinated international investigations with ^{15}N -labelled fertilizer to study the behaviour of the fertilizer nitrogen residue, i.e. that part (sometimes more than half) not usefully taken up by the crop. A part, incidentally, of a vital and increasingly costly agricultural input, especially for developing countries. How much of the residue gets returned to the atmosphere by soil "denitrification" processes and how much gets leached from the soil into local ground, surface or even drinking waters? It has already been established that the

levels of inorganic nitrate have shown a significant rise in certain ground and surface waters and in certain cases actually exceed WHO recommended limits for potable waters. The new programme is especially concerned with these question. The answers are clearly of environmental and of economic significance.

Other environmental problems in which the use of stable isotopic tracers already represent a useful input are the fate and behaviour of industrial sulphur and nitrogen emissions into the atmosphere. It is now known that these can and do significantly affect the pH or acidity of rain over large areas and affect plant health and soil properties.

There are similar wide-spread problems relating to the behaviour of nitrogen in the pollution and eutrophication of inland water bodies. It is known for example that in some aquatic systems the removal of undesirable levels of nitrate can be accomplished by natural and, possibly, by artificially enhanced biological processes of denitrification. Such questions as these can only be answered by large-scale experiments under environmental conditions and their study with the stable isotopes of nitrogen is now feasible.

ISOTOPE TRACERS AS "MONITORING" TOOLS

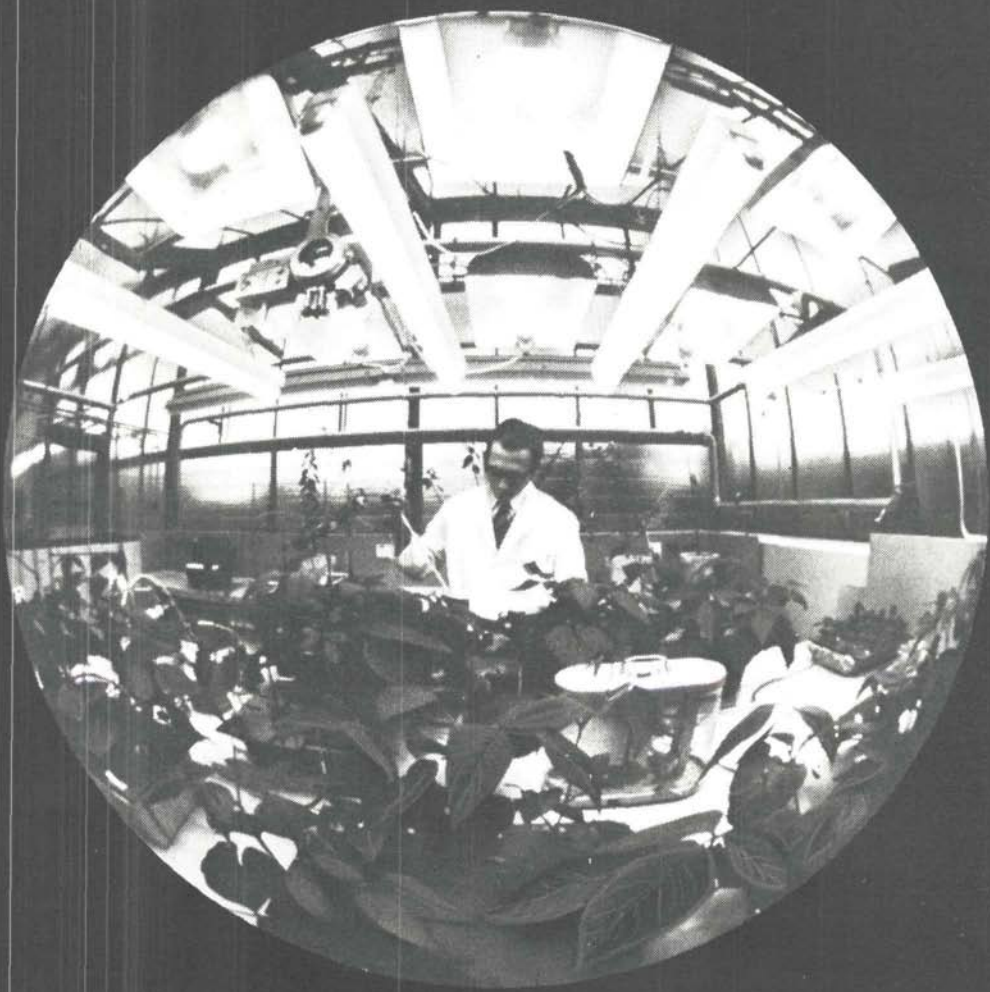
The "atomic energy industry", the testing of nuclear explosives, generation of nuclear power and fuel processing, have resulted in the appearance of radioactive substances themselves as trace contaminants of food, environment and living organisms on a global scale but, it should be stressed, at present equivalent to radiation levels very much less than those due to natural background radiation to which man has, and forever must be, exposed.

Radioecology

The instrumentation and methodology used in radioactive tracer research can, of course, be used as monitoring tools for existing environmental radioactivity. The data so obtained have provided unique information about behaviour and persistence in the atmospheric, terrestrial and aquatic environments. They have shown, for example, that the effective dilution of certain trace contaminants after absorption by the oceans is nothing like so large as the total volumes of the oceans might suggest, only the relatively shallow (30-metres) surface layers effectively acting as a sink.

Unlike many of the problems of chemical contamination those of radioactive contamination were anticipated from the beginning of the "atomic energy era". The corresponding studies led to the development of stringent standards, derived working limits, etc. for the protection of man and his environment. The great sensitivity and specificity with which radioactive contaminants could be studied (at much lower concentrations than those which could be determined by conventional chemical analysis) have provided a wealth of data not only upon the behaviour of the radioactive contaminants but on the behaviour of non-radioactive trace contaminants. Against this background it can be said that this field of "radioecology" and its associated radiological protection standards have themselves

"Radiotracer studies on metabolism and fate of pesticides ... are ... a necessary and critical step in understanding the persistence and action of a pesticide before it enters actual use." This photo shows a hothouse at the Institute for Botany and Microbiology, Research Centre, Jülich, FRG.
Photo: KFA, Jülich



provided a major contribution to the problems of human health and environmental quality protection in relation to non-radioactive as well as radioactive contaminants.

Radioactivation analysis

One result of the development of the atomic energy industry has been the proliferation of neutron, accelerated particle and radiation sources and their accessibility to scientists in many countries. Many elements can be readily determined with great sensitivity by irradiating them in the presence of such sources. This results in their excitation (e.g. gamma and X-ray fluorescence analysis) or in the formation of a radioactive isotope which can then be detected and often determined quantitatively. Of these techniques neutron activation analysis is the most important and widely used. Such photon and particle activation analytical techniques now have an established place in multi-element analysis methodology. Thus, potentially toxic elements such as manganese, vanadium, bismuth, copper, cadmium, arsenic, mercury or zinc can be detected at concentrations as low as one part in 10^{10} . Some advanced laboratories with access to the high neutron fluxes of the nuclear reactors have developed neutron activation analysis to a high degree of automation and applied it routinely to food and environmental media.

Radiolabelled substrates and reagents

It is under this heading that potentialities appear to be especially interesting in the context of environment. It is also here that applications appear to have lagged behind those of nuclear medicine. Some brief examples follow: —

An undesirable side-effect of certain environmental trace contaminants is their action on the genetic material of living cells and there is good evidence that such action accounts for the carcinogenic properties of some chemicals. During their evolution cells have developed defence mechanisms to remove damaged parts of the genetic material. These mechanisms are known as DNA (deoxyribonucleic acid — the chemical constituent of the cell nucleus which controls growth and reproduction) — repair mechanisms. Chemicals which inhibit DNA-repair are described as co-carcinogens. It is now possible to screen for potential DNA-repair inhibitors by studying their effects on the incorporation of radioactive thymidine (a DNA precursor) of cell DNA preparations in the laboratory. These techniques represent a major advance in the important search of mutagenic properties of potential carcinogens and co-carcinogens.

Many undesirable environmental contaminants and toxic substances injure the living animal or plant organism by the inhibition of vital enzymes (biological catalysts). The inhibition of an enzyme is invariably determined as a reduction in its ability to transform its normal chemical "substrate". Fortunately some enzymes become measurably inhibited at concentrations of contaminants very much lower than those which cause signs of poisoning. The sensitivity of such measurements can be increased in many cases by using a radioactive substrate for measuring activity of the enzyme. Thus, it is possible to detect human exposure to certain insecticidal poisons well in advance of possibly significant health affects. Techniques of using carbon-14 labelled acetylcholine as an indicator substrate for cholinesterase activity of finger-prick samples of human blood for detecting the exposure of farm animals and wild-life to carbamate and organophosphorus insecticides under trial for locust control have been developed and used. It is also under development for detecting undesirable exposure of cattle to acaricides for cattle tick control by carbamate

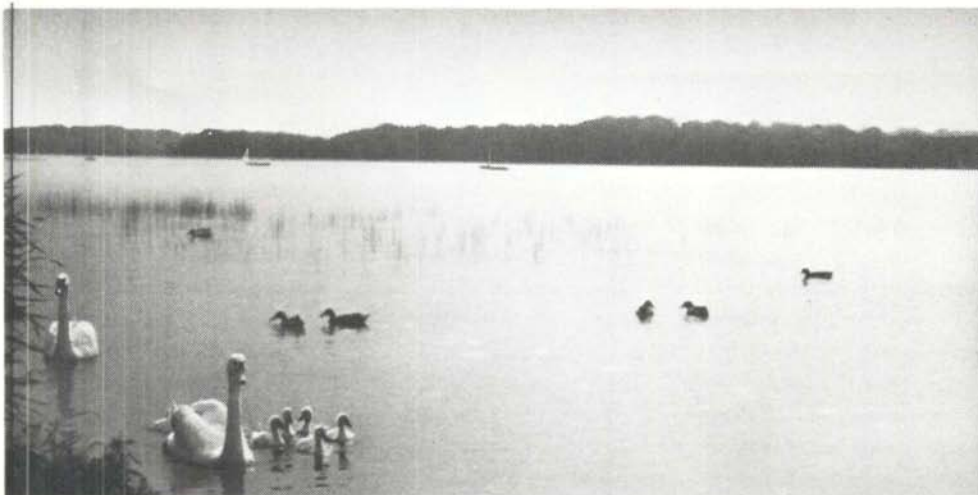


Figure 3: Tranquility on the surface but dying fish below. Labeled substrate techniques can indicate critical changes at the fundamental microbiological levels of aquatic food chains.

or organophosphorus acaricides. This radiometric technique is probably the most sensitive possible for detecting sub-clinical effects of many environmental insecticide residues.

An important application of the labelled substrate technique is that of using simple substrates such as carbon-14 labelled bicarbonate or phosphorus-32 labelled phosphate as an indicator of algal and other microbiological activity in water samples. Eutrophication of a lake, for example, depends at this "primary trophic level" on the ability of phytoplankton to utilize mineral constituents in their photosynthetic growth and production. This utilization is stimulated by increasing levels of nitrogen and phosphorus as a result of contamination and can effectively initiate the whole chain of biological events which lead to eutrophication and the reduction of useful fish populations. (cf. **Fig. 3.**) These techniques have been extensively studied and a recent Joint FAO/IAEA Advisory Group has recommended their co-ordinated exploitation as an indicator of undesirable changes in lakes, reservoirs, etc.

In the "labelled pool" technique metabolic intermediates of the tissues of a living animal or plant can be labelled by providing the organism with a suitable radioactive precursor. The intermediates of the resulting "labelled pool" can readily be resolved (e.g. by chromatographic techniques) and determined in very small samples of tissue and the effects of environmental contamination or poisons on the metabolic pathways studied. This application is being used for studying the effects of atmospheric sulphur dioxide on sensitive plants. The author originally developed this technique for studying the effects of poisons on living insects and it was possible to detect effects in fractions of tissue equivalent to one hundredth part of the brain of one common housefly.

Radioimmuno assay of chemical residues

The appearance of a foreign protein (antigen) in the tissues of a living animal may stimulate the defensive production of a specific protein, called an antibody. Blood serum

containing such an antibody long after the original stimulus has the property of being able to combine either *in vivo* or *in vitro* with the antigen. Indeed, this is the biochemical basis of immunization by vaccination.

If the antigen is chemically combined with a trace contaminant (e.g. the insecticide parathion) it can be made to produce an antibody which is effectively specific for the insecticide. Thus, if the "anti serum" obtained from a specially treated animal is incubated with a known concentration of the radioactive contaminant but unknown concentration of the same contaminant the antibody-insecticide complex produced can be isolated and the proportion of labelled insecticide recovered in this form measured. This proportion will depend on the unknown concentration of competing but unlabelled chemical residue and so provide a highly specific method of analysis. This "radioimmuno assay" technique for chemical residues seems also likely to provide information on the side-effects of trace contaminants involving immuno response reactions such as allergies. There is also the possibility of such reactions playing a role in the serious problem of pest resistance to certain pesticides, the mechanisms of which in many cases remain unknown.

Environmental isotopic ratios

The accurate measurement of stable and/or radio-isotopic ratios of existing environmental contaminants can sometimes provide information, not only on the levels of contamination but on the location and nature of the source. Thus, measurement of the ratios of krypton-85 and tritium in the environment have provided a quantitative indicator of nuclear fission and atmospheric nuclear tests on a global scale and of their relative contribution. The measurement of natural $^{14}\text{N}/^{15}\text{N}$ ratios of soil nitrogen promises to provide an indicator of how much soil nitrogen may have been lost through denitrification as distinct from leaching.

CONCLUDING COMMENT

It has not been possible more than very briefly to illustrate the current status and potentialities of isotope techniques as an aid to food and environmental quality protection and research. Nevertheless, these applications together with those of nuclear medicine, may ultimately contribute more to human health and welfare than the development of nuclear power.

DISCLAIMER

The views expressed in this article are the author's and not necessarily those of the UN agencies mentioned.

Bibliography

IAEA and related publications which illustrate the use of isotope techniques in food and environmental quality protection and research:

IAEA	Reference Methods for Marine Radioactivity Studies	Technical Report Series No. 118	IAEA, Vienna, 1970 STI/DOC/10/118
IAEA	Nuclear Techniques in Environmental Pollution	Proceedings of a Symposium, Salzburg, 26–30 October 1970	IAEA, Vienna, 1971 STI/PUB/268

IAEA	Nuclear Activation Techniques in the Life Sciences 1972	Proceedings of a Symposium, Bled, 10-14 April 1974	IAEA, Vienna, 1972 STI/PUB/310
IAEA	Radioactive Contamination of the Marine Environment	Proceedings of a Symposium, Seattle, 10-14 July 1972	IAEA, Vienna, 1973 STI/PUB/313
IAEA	Laboratory Manual on the Use of Radiotracer Techniques in Industry and Environmental Pollution	Technical Report Series No. 161	IAEA, Vienna, 1975 STI/DOC/10/161 ISBN 92-0-165075-2
FAO/IAEA	Nuclear Techniques for Studying Pesticide Residue Problems	Proceedings of a Panel Vienna, 16-20 December 1968	IAEA, Vienna, 1970 STI/PUB/252
FAO/IAEA	Nitrogen-15 in Soil-Plant Studies	Proceedings of a Research Co-ordination Meeting, Sofia, 1-5 December 1969	IAEA, Vienna, 1971 STI/PUB/278
FAO/IAEA	Pesticides Residues and Radioactive Substances in Food: A Comparative Study of the Problems	Report of a Panel of Experts, Vienna, 12-16 October 1970	IAEA, Vienna, 1972 IAEA-144
FAO/IAEA	Radiotracer Studies of Chemical Residues in Food and Agriculture	Proceedings of a Combined Panel and Research Co-ordination Meeting, Vienna, 25-29 October 1971	IAEA, Vienna, 1972 STI/PUB/332
FAO/IAEA	Isotope Tracer Studies of Chemical Residues in Food and the Agricultural Environment	Proceedings and Report of Research Co-ordination Meetings Ispra, 30 October- 10 November 1972	IAEA, Vienna, 1974 STI/PUB/363
FAO/IAEA	Effects of Agricultural Production on Nitrates in Food and Water with Particular Reference to Isotope Studies	Proceedings and Report of a Panel of Experts, Vienna, 4-8 June 1973	IAEA, Vienna, 1974 STI/PUB/361
FAO/IAEA	Radiolabelled Substrates for Studying Biological Effects of Trace Contaminants	Report of a Research Co-ordination Meeting, Vienna, 8-11 October 1974	IAEA, Vienna, 1975 IAEA-170
FAO/IAEA	Isotope Ratios as Pollutant Source and Behaviour Indicators	Proceedings of a Symposium, Vienna, 18-22 November 1974	IAEA, Vienna, 1975 STI/PUB/382 ISBN 92-0-010375-8
FAO/IAEA/ WHO	Methods of Radiochemical Analysis	WHO Technical Report Series, 1959, 173	WHO, Geneva, 1966
FAO/IAEA/ WHO	Comparative Studies of Food and Environmental Contamination	Proceedings of a Symposium, Otaniemi, 27-31 August 1973	IAEA, Vienna, 1974 STI/PUB/348
FAO/IAEA/ LO/WHO	Mercury Contamination in Man and his Environment	Technical Report Series No. 137	IAEA, Vienna, 1972 STI/DOC/10/137