composed as it is of nations of widely differing cultures which are putting at your disposal a staff reflecting these differences, this staff nevertheless can form a body guided by similar principles, performing what is known as international civil service.

Finally, it gives one a deep satisfaction to meet so many personalities from different parts of the world and to try to bring about mutual understanding of common problems. But perhaps the highest reward given to us working in the Agency is the feeling that we are contributing to the breaking down of barriers and the building up of a collaboration and understanding in the scientific and technological fields. This in turn should pave the way for the practical statesmen to build international peace on firm foundations.

ISOTOPE APPLICATIONS IN HYDROLOGY

Water is a scarce commodity in many areas of the world. Because of increases in population and expansion of agricultural and industrial enterprises, water needs are rapidly mounting and many countries are now engaged on projects to develop water resources. In fact, the success of many current plans for economic development may well depend on the effective and judicious utilization of these resources. Hydrology has thus become a science of immense practical importance.

Hydrological problems, however, are not confined to water needs alone. The behaviour of water has important consequences on various kinds of agricultural and industrial activity, such as the construction of a dam or a hydroelectric power station. Hydrological studies, therefore, have many aspects and many purposes, and the relevant techniques are necessarily diverse.

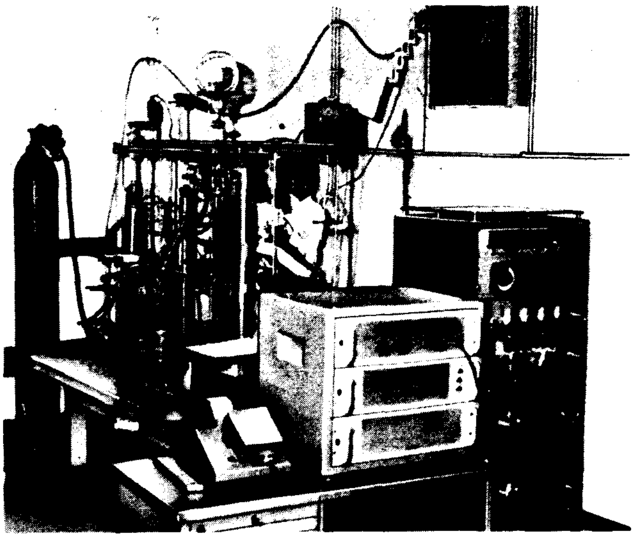
In recent years radioisotopes have enlarged these techniques and in some cases made them more efficient and accurate. The use of isotopes has also made it possible to develop certain new techniques for the study of hydrological problems. A few simple examples will illustrate their role.

Isotopes used as tracers can, for example, be used to measure the rate of flow of water in canals, closed conduits and rivers. Chemicals have been used for this purpose for a long time; isotopes, though used on the same principle, are far more sensitive to detection and have hence made the measurements more convenient and accurate. Again, the tracer function of radioisotopes can be successfully employed in studying the siltation of rivers, estuaries and harbours; in fact, this has been done in many countries for a number of years. For the study of groundwater resources, which is of great importance in arid or semi-arid areas, isotope uses are opening up new possibilities not only for tracing the movement of water underground but also for assessing the amount of water in a particular groundwater body.

There are several other hydrological applications to which isotopes have been put, and many others which can be possibly developed. These current and potential applications constitute one of the major scientific areas in which the International Atomic Energy Agency can play a useful role, and the Agency has already started a comprehensive programme of work in this field.

Tritium Measurements

One of the first major projects undertaken by the Agency is a survey of the concentration of hydrogen and oxygen isotopes in water. The aims of this project are to study the circulation pattern of water vapour on a global scale and to measure the tritium concentration of rain water in different parts of the world, which is necessary for the application of environmental tritium to local hydrological problems. Tritium is produced in nature as a result of reactions in the atmosphere brought about by cosmic rays and is brought down by precipitation of water vapour, that is by rainfall. Since the amount of tritium normally present in water as a result of this process can be calculated, the absence of tritium or a lower-than-normal concentration in a particular water body would indicate the radioactive decay of the original tritium without any fresh injection of tritium from rain. In other words, this would indicate that the water is old. And since the rate at which tritium (which has a half-life of 12.5 years) decays is known, the measurement of tritium can reveal the age of a given water sample.



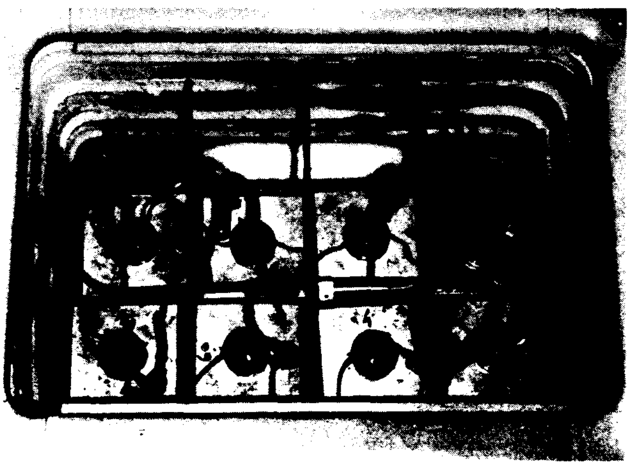
Gas counting of tritium in the laboratory at IAEA headquarters

Apart from this natural process, a substantial amount of tritium has been introduced into the atmosphere in recent years as a result of thermonuclear explosions. The testing of hydrogen bombs releases tritium in the atmosphere, which finds its way into the earth's water bodies, again through precipitation. The presence or absence of this tritium can also be used for water dating, that is determining the age of a particular water sample.

Tritium measurements are thus expected to yield valuable information on the age of different water bodies and the rate at which they are replenished by precipitation. The information would be of great help in planning the development of water resources for irrigation or industry.

The Agency's tritium survey project, which is being carried out in co-operation with the World Meteorological Organization, is now well under way.

Electrolysis cells for concentrating tritium in the Agency's laboratory



Samples of rain water are collected monthly at some 100 stations all over the world and analysed for their tritium concentration at some advanced laboratories and also in the Agency's laboratory. The Agency has furnished the laboratories with tritium standards to facilitate accurate analysis of the samples.

In many experiments tritium is artificially added to water to serve as a radioactive tracer. Tritiated water, that is water tagged with tritium, is an extremely useful tracer in a variety of hydrological investigations. For example, in places where water disappears underground and then appears in springs some distance away it may be necessary to know whether a particular spring or group of springs is fed by a particular source of water disappearing underground. Tracer applications of tritium can ascertain such interconnections as well as such other aspects as the rate and direction of flow and the amount of water stored underground. Under a United Nations Special Fund project, the Agency carried out a tritium tracer experiment in Greece. Water samples collected from this experiment have been analysed at the Agency headquarters in Vienna and a number of important findings have already been obtained.

Similar projects are also sponsored or supported by the Agency by means of research contracts. Under one contract, tritium tracer experiments have been carried out in the Trieste area. Several other research contracts dealing with the hydrological applications of radioisotopes have been awarded to laboratories or scientific institutes in different countries. The growing interest in this type of investigation can be gauged from the fact that the amount allocated for the Agency's research contracts for isotope applications in hydrology has risen from some $30 000 in 1962 to approximately $40 000 this year.

An international conference on the applications of tritium in physical and biological sciences was held by the Agency last year.

Panel Discussions

To help in formulating its overall programme of isotope applications in hydrology, the Agency convened two panels of experts - the first in 1961 and the second last year. At their meetings at the Agency's headquarters in Vienna, the members of the panels examined all the main aspects of the subject, assessed the present state of development and discussed possible lines of improvement and expansion. After the meetings of the first panel, the experts felt that the technical aspects discussed by them should be summarized in a comprehensive report for their own use. It was later found that the report, which combined the experience of isotope specialists who were not very familiar with hydrological questions with that of hydrologists who were not directly concerned with isotope applications, would be of much wider interest. The report has therefore recently been published in the Agency's Technical Reports Series.

The main subjects discussed in the first report are: (i) radioactive tracers for water, (ii) stable isotope tracers for water, (iii) dating of groundwater by using radioactive isotopes, (iv) pulse method for groundwater bodies, (v) methods of groundwater tracing, (vi) stream discharge measurements, (vii) isotope applications to hydraulic problems, and (viii) some problems in hydrology to which isotope methods could be applied. Under each of these headings, the problems are first stated and the information and ideas presented by the panel members then summarized. Finally, on each subject the report embodies certain "conclusions and recommendations", summing up the present situation and suggesting lines of further development. The last chapter of the report deals with some intricate hydrological problems where isotope techniques could profitably be used.

Much of the work of the first panel was in the nature of a broad review of outstanding problems and of current and possible techniques for their solution; it examined the available isotope techniques and considered how they could be developed to deal with water problems. During the meetings of the second panel last December, the emphasis was more on actual applications, especially in groundwater studies.

The panel felt that groundwater development seemed to be the most promising area for the application of isotope techniques. It, however, noted that while in surface hydrology these techniques were already available in a form in which they could be readily used by hydrologists, no such methods had yet been established for groundwater studies. Members of the panel thought that it might be useful to prepare manuals describing isotope techniques for groundwater development and their applicability.

Examining the available techniques, the panel discussed the various radioactive tracers that could be used for groundwater dating. Apart from tritium, the use of carbon-14 (radioactive carbon produced through cosmic ray-induced reactions in the atmosphere), silicon-32, sodium-22 and the natural radioactivity from isotopes in the uranium and thorium series were considered. The panel also discussed the use of radioisotopes for surface water tracing, for example in river discharge measurements. Another subject considered was the possible application of stable water isotopes in hydrological studies; since the ratios of these isotopes vary with altitude, stable isotope techniques could be usefully employed in ascertaining the origin of a water sample.

The technical part of the panel discussions will be incorporated in the second comprehensive report which is now under preparation. As regards the Agency's role, the panel stressed the need for increased activity to promote isotope applications in hydrology, especially through the development of routine techniques.

Symposium in Tokyo

The work of the second panel was followed up within three months at an international symposium held by the Agency on the application of radioisotopes in hydrology. The symposium, which met in Tokyo from 5 to 9 March, was attended by about 100 scientists from 14 countries (Australia, France, the Federal Republic of Germany, Indonesia, Iran, Israel, Italy, Japan, the Netherlands, the Philippines, Sweden, Thailand, the United Kingdom and the United States of America). Representatives of the Economic Commission for Asia and the Far East (ECAFE), the Food and Agriculture Organization (FAO), the International Union of Geodesy and Geophysics (IUGG) and the World Meteorological Organization (WMO) were also present.

Twenty-seven papers were presented and discussed at the meeting, dealing with the use of isotope techniques in problems concerning both surface and groundwater. The subjects of discussion included river discharge measurements, mixing processes in rivers and lakes, silt and bed load transport, speed and direction of flow of groundwater, and age and recharge rate of groundwater.

River Flow and Mixing

A comparison of different isotopic methods for river flow measurement was given in a paper by two British scientists, G. C. Clayton and D. B. Smith. The Dilution, Continuous Sample and Total Count Methods - the three techniques discussed in the paper - are already well established for flow measurement in closed conduits, but their application to river flow has not yet been so widely tested. The authors described results obtained with these methods in measurements carried out in a small stream and two small rivers in the United Kingdom.

All the three methods involve the introduction of a radioactive tracer at a certain point in the stream and measurement of the activity in the water at another point downstream. In the Dilution and Continuous Sample methods, samples of water are taken to measure the concentration of the radioisotope and then compare it with the original concentration in the tracer, but while the former involves the injection of the tracer at a constant and known rate over a period of time, the latter requires a single, rapid injection of a known quantity. There are also some differences in the sampling and measuring procedure. As for the third method, the distinctive feature is measurement by counters inserted into the stream at the sampling point, instead of the samples being removed for analysis.

The correct choice of the sampling point is important in all the three techniques. If it is too close to the point of injection for adequate mixing of the tracer in the stream to have taken place, the assay of the samples cannot provide a correct measurement of the rate of water discharge. On the other hand, if the sampling point is too distant, excessive dispersion occurs and the tracer is over-diluted for optimum measurement. As regards the choice of tracer, a major limitation is imposed by possible adsorption of the radioisotope by matter in suspension in the stream or by material of the river bed. Adsorption depends both on the choice of tracer and on the geological nature of the river bed.

After discussing the various technical requirements in the light of their own experiments, Mr. Clayton and Mr. Smith expressed the view that the Continuous Sample technique is preferable to the other two methods, especially because of its operational convenience and flexibility. As regards tracers, their finding is that sodium-24 and bromine-82 can be readily used but phosphorus-32 is highly adsorbed. In many respects, tritium is ideal; it is not subject to adsorption, is available in high specific activity and is not expensive. In spite of its long radioactive half-life it is one of the least toxic isotopes. One disadvantage, however, is that it is difficult to measure. It emits beta particles of low energy and hence requires specialized laboratory equipment for accurate measurement. In the opinion of the two authors, it should be used for river discharge measurements only when the use of gamma ray emitting isotopes is not convenient.

A paper by five French scientists (J. Guizerix and others) described experiments with the total count method in measuring the discharges of rivers and of hydroelectric plant penstocks. Their procedure was to sample a portion of the current during the passage of the radioactivity by means of pumps and constant-level tanks.

British and French scientists also reported on experiments carried out with isotopic tracers to determine mixing processes in rivers and lakes. Among the investigations described were measurements of fallout radioactivity in the Lake of Geneva and a study of water movement in a natural underground pool, semi-tidal and partly saline. The latter, it was pointed out, would assist engineers to design a method for extracting potable water from the pool.

Five Japanese scientists (M. Kato and others) reported that radioactive tracer experiments had been made on the Sorachi River in Japan to obtain precise information on the flow times and flow conditions of water released from a multipurpose dam. The investigation, which had been carried out with sodium-24, had produced data which would be of value in the utilization of the water for irrigation.

Movement of Sediment

The use of radioactive tracers to assess the movement of silt and bed lead, i.e. of matter in suspension and of the sediment on the river bed, was one of the important subjects considered at the symposium. It is now about ten years since radioisotopes were first used to investigate the siltation of harbours, rivers and estuaries. Labelled sand can be placed on the river bed and its movement traced with submerged counters suspended from boats. This method, however, does not give much more than a qualitative picture of what happens to the labelled sand. Present work is directed towards putting this method on a quantitative basis so that one may be able to measure how much sand is transported, for example, along the bed of a river. The potential value of this approach will be apparent if one remembers, for example, that the rate at which silt builds up against a dam is a limiting factor upon the life of that structure.

Certain lines of current research aimed at developing a quantitative method of measuring sand transport were discussed in a paper by G.H. Lean and M.J. Crickmore (UK). As a first essential, they pointed out, the tracer chosen to represent the movement under study must behave in the same way as the sediment in the hydraulic processes. Sand particles, with their surface labelled with a radioisotope by adsorption from a radioactive solution, have been employed by some investigators. However, owing to the vulnerability of the surface label to abrasion, glass particles, incorporating an element which on irradiation possesses the desired radiation properties, are often preferred for long-term experiments.

Mr. Lean and Mr. Crickmore stated that there are four main ways in which the discharge of sand or silt particles along a channel can be measured by tracers. These may be called the space integration method, the time integration method, the steady dilution method and the cloud velocity method. Except for the first, these methods have their counterparts in the measurement of the discharge of liquids.

In the first method the sample is injected at a section and, after a time long enough for the particles to "forget" their initial situation and wander over the whole field, the velocity of their centre of gravity is determined by making successive measurements of their concentration in space. In the second method the concentration is measured at a fixed section which is sufficiently far downstream for the initial circumstances of injection to be lost and for the particles to have taken up the average velocity of the particle flow. The steady dilution method is a variant of the second method in which the injection is continuous at a constant rate. The cloud velocity method is essentially the same as the first method but in its application to the flow of liquids it has been more usual to measure not the successive distributions of the dilutant in space but the average time for its passage between two sections.

It was reported that experimental work had been carried out in a laboratory channel on some of the above methods, employing tracer sand grains of different sizes in transport in a rippled sand bed. The laboratory experience has shown that the difficulties of measuring sand and silt transport in rivers using tracers are formidable and, although all the four methods can be applied, each has its peculiar difficulties. It seems likely that the choice of method or combination of methods will depend very largely on the needs and characteristics of a particular situation.

Methods of measuring the transport of sediment in alluvial rivers were described in a paper by J. E. Chabert and others (France). They stated that the first tests, which were purely qualitative in nature, had been made on the Niger in Mali and on the Loire in France. These were aimed at obtaining information on the development of zones of sediment transport in relation to liquid discharge, on the formation of bars and on the rate of advance of dunes. Later, attempts were made to develop quantitative methods which would accurately determine the amount of sediment transported, and experiments were carried out on the Rhone and the Loire.

Contribution to Groundwater Studies

The place of isotope methods in groundwater research was reviewed in a paper by four Isreali scientists (Y. Harpaz and others). They classified the different isotope techniques, compared them with conventional methods, and showed that in certain cases the former could not only replace and improve upon some of the existing methods, but might provide more immediate answers to some hydrological problems. Some of the main points of this review are as follows:

The techniques can be classified according to the isotopes used or according to the principle of application. The principal isotopes in use are:

(a) certain stable water isotopes, such as heavy hydrogen (deuterium) and oxygen-18;

(b) tritiated water;

(c) other radioisotopes produced in the atmosphere and introduced into water by natural processes;

(d) naturally occurring isotopes of the uranium or thorium series; and

(e) artificially injected isotopes (other than tritium).

So far as the principles of application are concerned, the methods can be considered under three headings: dating, pulse tracing and isotope analysis. The dating methods rely on the unique property of radioactive decay and involve a comparative measurement of the change in the specific radioactivity of an isotope between an input point and the point of analysis. The input can be an area where a groundwater system is recharged by rain or the point of transition from an adjacent system. The most useful isotope for groundwater dating so far has been the cosmic ray-produced tritium, which labels rain with a tritium content that is characteristic to a particular locality. Other isotopes, such as carbon-14, have also been proposed as dating tools for groundwater. Tracing is the process of relating the changed concentration of an isotope at the place and time of measurement to that at a known injection point and time. Isotope analysis is based on relating the concentration of some identifiable component of water body to the characteristic concentration of this component in some source. Any characteristic identifiable water component, such as dissolved salts, trace elements, stable isotopes of oxygen and hydrogen, as well as the radioactive dating isotopes, can be utilized for this purpose.

An evaluation of the contribution of these methods to hydrological research shows that:

(a) nuclear analytical tools, such as activation analysis of trace components in water or rocks and bore-hole logging with neutrons or gamma rays, have been useful aids to existing classical research methods;

(b) isotopic materials have added a new method - dating - to the research methods formerly available to hydrologists, and have added new dimensions to the tracing techniques; and

(c) the three principal isotope methods have in many cases enabled a direct solution of engineering problems without necessitating a complete hydrodynamic description of the system concerned.

Certain specific fields of application will illustrate these points. In determining the existence and extent of groundwater bodies, the established methods of looking for water in a bore-hole or detailed geophysical prospecting are costly and slow, and isotope methods can be of advantage at a preliminary survey stage. Dating and isotope analysis can also contribute to the determination of the origin of some water body. Other useful applications include the determination of interconnections between a water source and an adjacent water body, assessment of the dispersion of a moving body of water through a porous medium, and measurement of the direction and velocity of water in an aquifer.

Almost all such applications are in some sense tracer studies, and the advantages of isotopes as tracers are numerous. Apart from the fact that isotopes of different chemical and radioactive properties can be used to suit each particular situation and extremely sensitive detection methods are available for their identification, the inherent time factor of radioactive decay provides all radioisotopes with a memory, so that one single measurement can replace extended periods of hydrological observations. Another advantage is that tritium, heavy hydrogen and oxygen-18 are isotopes of the water elements and hence ideal tracers for the unperturbed identification of water bodies.

In summary, it can be stated that the contribution of isotopes to the determination of hydraulic parameters is limited; that all characteristics related to water movement can, however, be most directly measured by tracing methods in general and isotope tracing in particular; and that those characteristics in which the actual travel path of individual water particles must be followed can only be evaluated by the use of isotope tracers. Since the last feature is important in problems of waste treatment and quality improvement of water, isotope methods can contribute significantly to the solution of these problems.

Some Groundwater Applications

R.W. Nelson and A.E. Reisenauer (USA), in a paper on the application of radioactive tracers in scientific groundwater hydrology, pointed out that radioactive materials could help not only in making conventional studies of groundwater flow but possibly also in carrying out comprehensive, refined analyses of groundwater flow systems. Although the immediate need for such detailed studies appears to be restricted to special situations (e.g. radioactive waste disposal) where a near-exact knowledge of travel time is desired, it may well be that they will find many other useful applications in the future.

C.V. Theis, also from the USA, stated that tracers give a direct approach to the problems of movement of contaminants in groundwater and probably the most useful approach to problems of dispersion in the field. He noted, however, that tracers could not provide a short cut in the absence of other hydrological data.

H. Moser and F. Neumaier (Fed. Rep. of Germany) emphasized the importance of the filtration rate in groundwater studies and discussed isotope techniques for measuring it. They showed how these tracer studies could help in determining the course and extent of seepage flow under storage dams.

The use of tritium in groundwater tracing in Greece, which was carried out with the help of IAEA, was described in a paper by the international team of scientists responsible for the project (D.J. Burdon and others). The aim of the project is to determine, test and demonstrate methods for the development of groundwater resources in limestone terrain. One of the areas under investigation is that between the high plateau of Tripolis and the plain and Gulf of Argos in the Peloponnese. The surface drainage leaves the plain through a number of sinkholes, and there are a number of springs near the coast about 30 km away.

In order to utilize the groundwater in the limestone and possibly intercept that water which is being lost to the sea, information was required on the following points:

(a) which sinkhole feeds which spring or group of springs;

(b) what is the groundwater residence time between the sinkholes and the springs; and

(c) how much groundwater is stored between the sinkholes and the springs.

Tritium was used as a tracer for this investigation, and in March 1961 1000 curies of tritiated water was introduced into one of the main sinkholes. Samples of water from the springs were collected and analysed for tritium in a liquid scintillation spectrometer at the Agency's laboratory in Vienna. Tritium has been found in the water from one of the springs and an interconnection thus established. The amount of tritium found in the samples and the period of time over which it has appeared have also given a tentative indication of the amount of water stored and the underground residence time. In a second experiment, 400 curies of tritiated water was added in February 1962 to the water flowing into another sinkhole. After seven days tritium appeared in one of the coastal springs. The tritium content of the spring water reached its maximum concentration on the second day; no further tritium was detectable nine days after its first appearance and no tritium has so far been found at any of the other sampling points. Here, too, certain tentative conclusions have been drawn regarding the amount of water stored between the sinkhole and the spring as well as the time and rate of flow.

During the discussion on measurements of age and recharge rate of groundwater, papers were presented on the uses of both tritium and carbon-14. In a paper by J.C. Vogel (Netherlands) and D. Ehhalt (Fed. Rep. of Germany), it was pointed out that in view of the extremely slow movement and long storage times of groundwater, carbon-14 (which has a half-life of 5700 years) appears to be a very promising tool of investigation. The isotope is present in groundwater in the form of dissolved bicarbonate and, subject to certain conditions, could be used to determine residence times of up to some 40 000 years.

In another paper, J.C. Vogel and others gave the results of a preliminary survey of fresh water isotopes in South Africa. The semi-arid climatic conditions in South Africa make the isotopic composition of rain, river and groundwater considerably different from that in Europe and the United States.

Analyses of some samples of Kalahari groundwater did not reveal any significant amounts of tritium and it was concluded that the water from which the samples were taken must be more than 40 years old. One sample was found to contain tritium, which means that the water in the reservoir has an average age of about 30 years or that a small amount of tritium from thermonuclear tests has entered the supply.

Some miscellaneous applications were discussed at the last session of the symposium. These included hydrological investigations with the help of radiostrontium and radiocaesium from nuclear fall-out.

In a closing address, the Agency's Director General, Dr. Eklund, stressed the importance of isotope techniques in groundwater studies. The meeting, he said, had also shown "that the range of applications of radioisotope techniques to hydrological problems is likely to grow considerably in the years ahead". He suggested that governments should consider the application of these techniques while planning projects for the study or use of water resources.

FERTILIZER APPLICATION TO RICE

DIFFERENT METHODS EVALUATED BY ISOTOPE TECHNIQUES

The first results are now available of a research programme on the application of isotope techniques to rice cultivation which was initiated by the International Atomic Energy Agency over a year ago. Work done under a number of research contracts awarded by the Agency as part of the programme has produced important findings on the relative merits of different mthods of applying phosphate as a fertilizer for rice.

The range and depth of agricultural investigations which have been made possible by the use of radioisotopes are now widely known. In general it can be stated that the application of isotope techniques is gradually leading to a detailed understanding of the chemical, biological and other processes to determine the success or failure of an agricultural enterprise, and this understanding in turn provides a certain basis for the adoption of improved cultural practices. Nowhere perhaps is this more evident than in the contribution of isotope techniques to the study of the supply and movement of nutrients and their uptake and metabolism by plants.

While any major change in cultural practices should be based only on a thorough study of all the processes involved, the results of some of the investigations may be of immediate practical interest. To take a specific case, any information on the relative efficiences of the different methods of fertilizer placement - whether, for example, it should be placed on the soil surface or at a certain depth - would be of direct interest and value to farmers.

The need for such information in regard to phosphate application to rice plants is particularly urgent. Several years of classical field experimentation have failed to produce unequivocal results as to the relative efficiences of the different methods of phosphate placement in rice cultivation. This, however, is not surprising. The variations in yield between different plots of a field experiment are not very large. Although the utilization of the phosphate may be quite different, the yields are usually so close to the optimal phosphate response that a comparison of the yields cannot provide an accurate and sensitive measure of efficiency of phosphate utilization for the different placement methods. If, however, superphosphate labelled with radioactive phosphorus (phosphorus-32) is used for such an experiment, it is possible to determine the fraction of phosphate in the plant derived from the fertilizer. In this way the efficiency of phosphate uptake can be determined directly and independently of the vegetative development or grain yield of the crop.

During the eighth meeting of the International Rice Commission, held in New Delhi in December 1961, a number of research workers indicated to the IAEA representative that they would like to use isotope techniques for a comparison of various methods of phosphate placement in rice cultivation. Within three months the Agency's Unit of Agriculture, in co-operation with research workers in several Member States, designed a field experiment and arranged for the supply of labelled phosphate fertilizer. Seven research contracts were concluded with