Dr. DARKO STOŠIĆ, from Belgrade, Yugoslavia, studied six months at the All-Union Institute of Experimental Veterinary Science, Laboratory of Animal Physiology, Moscow, under an Agency fellowship. The Head of the Laboratory was Dr. Alexander Kudriavtsev.

Dr. Stošić studied in particular the metabolism of phosphorus-32 in hens and ruminants. He also visited other Soviet agricultural institutes in Moscow and Leningrad. Dr. Stošić is an adviser to the Yugoslav Federal Nuclear Energy Commission on agricultural questions. He plans and co-ordinates the work on agricultural applications of atomic energy in Yugoslavia and conducts scientific experimental research in the fields of animal nutrition and applied physiology.

Dr. Stošić writes that during his training in Moscow he "studied the organization of scientific work with radioisotopes in agriculture and the methods of experimental work in this field. This training helped me to improve my knowledge of the organization of scientific work" which, he writes, will help him to "improve my scientific work and in training my collaborators".

USE OF ISOTOPES IN HYDROLOGY

Water is often spoken of as the most important commodity of human societies. It is, of course, not possible to make a gradation of basic necessities - sunshine, for example, is important also. Nevertheless, it is clear that where water is lacking in its patchwork distribution over the globe, human settlement is generally impossible. Further, in areas where water is scarce living conditions can certainly be improved if it is made available in greater quantities.

This has been recognized for centuries and in ancient times the art of water management was considered more or less the key to progress. Most of the water then used by man was drawn from neighbouring rivers, but more accessible parts of the groundwater were also utilized.

Measuring flow rate of water in UN Special Fund ground water project in Greece (Photo: Greek Atomic Energy Commission)

In our time groundwater is being utilized on an increasing scale. This has brought benefits but it has also created problems. Groundwater resources are obviously not inexhaustible and proper planning for the future must consider to what extent they should be tapped. Such determinations have not been easy to make. Although hydrology, both as a science and as an engineering art, has developed rapidly, it has until recently lacked the tools needed for thorough groundwater exploration. With conventional hydrological methods, for example, it is not in general possible to assess the rate at which groundwater reservoirs are recharged, and in many cases it is difficult or impossible to estimate the amount of groundwater stored in a certain area. Therefore, these two problems - how much groundwater is in an area and what is the recharge rate - are repeatedly encountered by hydrological engineers. Radioisotope methods seem to be promising tools for solving the problems.

Radioisotopes can be applied to hydrological studies in two principal ways: as a tracer to identify water, or as an age measuring device. Applications of each method are discussed in the following paragraphs.

Tracing Water with Radioisotopes

Radioisotope tracers are added to groundwater in order to determine such characteristics as the water's rate or direction of flow. Techniques for conducting such studies are being developed satisfactorily. The main problem has been to find a tracer with a suitable half-life - neither too short nor too long - which is at the same time easy to detect and not absorbed by minerals in the ground. A number of different tracers have been tested, but more work along these lines is still required. Tritium has proved to be a most effective tracer of water, but still offers two difficulties. One is that the radiation given off by this isotope is so weak that detection analysis cannot be carried out in the field. The other is that tritium's half-life, 12.5 years, is rather long for short-term experiments. Other isotopes which behave reasonably well as water tracers, if certain precautions are taken, are iodine-131, iodine-125, and the cobalt-60 cyanide complex.

It is possible to arrange tracer experiments in such a way that they give information on the amount of underground water storage in a given area. The Agency is now engaged in tracing groundwater in a karstic region* of Greece, the Tripolis plain on Peloponnesus. Drainage from the plain takes place by means of small rivers which enter so-called katavothres, i.e. sinkholes in the bordering mountains. What happens to this water is so far unknown. Numerous springs close to, and even in the sea, indicate the presence of an extensive underground drainage system, possibly in the form of underground rivers. An experiment utilizing radioisotope tracers established the connexion between one of the sinkholes and a spring. The data obtained also made it possible to estimate the amount of underground water storage between these points. Water in a second sinkhole was similarly labelled in February of this year.

The Agency is also sponsoring other experiments in karstic regions to obtain more information on this common type of groundwater storage which is so difficult to investigate using conventional methods.

In the experiments mentioned above the tracer, tritiated water, is added during a short time, as a kind of pulse, to the water which enters the underground system. In principle one could do the same type of experiment in regions where groundwater is fed by precipitation slowly seeping into the soil. In such regions, however, practical difficulties arise because the area through which the groundwater is fed is generally very large.

An alternative method for estimating the amount of groundwater in a given area is to utilize tritium which has been released into the atmosphere in weapons tests. One needs only records of the amounts of tritium carried down by precipitation and carried away by rivers at different times. We can regard the tritium entering with precipitation as a pulse of a certain shape with respect to time. This shape is distorted when the pulse passes through the groundwater reservoir. The extent of this distortion indicates the amount of water of various ages in the ground.

Realizing that this man-made tritium has potentialities in meteorology as well as in hydrology, the Agency, on the recommendation of its Scientific Advisory Committee, has initiated, in co-operation with the World Meteorological Organization, a world-wide survey of the isotopes of water, including tritium, contained in precipitation. Precipitation is collected monthly at some 90 stations all over the world. Samples are analyzed for tritium at certain laboratories. With the information obtained it will be possible to determine the extent of the tritium pulse added in any area at any time. WMO has also been requested to co-operate in a similar survey of river water. By putting the precipitation and river results together, estimates of groundwater reservoir sizes can be made for the main river basins of the world.

Similar sampling of river waters could be undertaken in all areas where information on groundwater storage is desired. At present there is a shortage of laboratories which have the rather costly equipment required for tritium analyses of water samples. This lack can be made up with time; important now is a sound sampling programme, and this is inexpensive.

Using Radioisotopes to Measure Age

As is well known, the isotope carbon-14 has been used for many years to date archaeological specimens. It is produced in the atmosphere by the reaction of neutrons originating from cosmic radiation with atmospheric nitrogen. It seems to be produced at a constant rate and enters vegetation in much the same way as ordinary carbon. Once incorporated into organic matter it slowly decays so that the concentration which remains enables one to compute the time which has elapsed since carbon-14 was first taken from the atmosphere and incorporated into the plant.

It is important to be able to measure the age of groundwater bodies if the groundwater is to be used by man since this gives one an idea of the likely replenishment rate. The use of tritium has been suggested for this purpose. Tritium is produced in the atmosphere by the same process as carbon-14, and, after entering the ground as part of the water molecule, decays, so that its concentration, like that of carbon-14, decreases. In principle, therefore, it should be possible to utilize tritium to date groundwater samples in the same manner as carbon-14 is used to date archaeological specimens.

There are, however, a few complications. One is that the tritium balance in nature has been strongly disturbed by the man-made tritium which has been introduced into the atmosphere in large quantities since 1954. Thus, the radioactive decay method cannot be used to determine the age of groundwater samples less than eight years old.

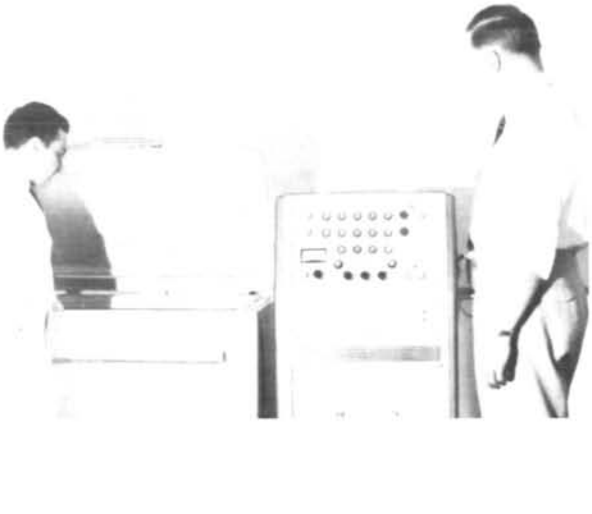
Another possible complication is that there may have been appreciable mixing between waters of different ages. Fortunately, mixing in groundwater appears not to be serious, judging from recent investigations in the United States where a very marked stratification of tritium of different ages was found in a groundwater body. Thus, provided a proper sampling technique is used, it should be possible to date

* *Karstic regions are limestone regions marked by sinks and interspersed with abrupt ridges, irregular protuberant rocks, caverns and underground streams.*

water at different points in a groundwater body, at least within the time range 10 to 50 years. With such information the average age of a groundwater body can be assessed. Ages much greater than 50 years would be indicated by practically a complete absence of tritium. Such cases have, in fact, been recorded.

As an example of the value of tritium determination of groundwater age, the case of the Sabi River Valley in Southern Rhodesia can be cited. Test drilling there showed abundant water in the ground. It also showed that the water table slopes away from the river toward a mountain range with no visible outlet. This was hard to explain, since the valley is filled with rather coarse material, and a subterranean river through the mountain range would be required for any substantial flow. A few samples of the groundwater from some boreholes and a sample from the river which was thought to feed the groundwater were analyzed for tritium. The analyses were striking in that the groundwater samples, including one taken from a borehole only about one kilometer from the river, showed no tritium, whereas the river water showed the expected concentration of tritium. Based on the known half-life of tritium, and the accuracy limits of the analysis, one can conclude that it must have been at least 50 years since this groundwater left the nearby river. Thus one can surmise that in this area groundwater moves extremely slowly despite the slope in the groundwater surface, presumably because of strata of clayey material in the sand. These findings have serious practical implications regarding any future intention to irrigate the area. If river water is used for irrigation, there is danger that the salts normally present in river water will accumulate, since the groundwater moves too slowly to wash them away. (This is apparently the explanation for the accumulation of salt which has occurred in West Pakistan over the last half century.) If, on the other hand, groundwater is pumped for irrigation purposes, it may rapidly be used up, since it does not seem to be easily recharged from the river. One can conclude that in a case like this a rather extensive investigation of the rate of movement of groundwater over the whole area should be undertaken before the area is developed for agriculture.

Equipment for analysing water samples at IAEA Laboratory



Taking water samples for tritium analysis in UN Special Fund ground water project in Greece (Photo: Greek Atomic Energy Commission)

Methods for dating water other than tritium analysis have been suggested recently. One is that carbon-14 could be used for dating old groundwater since groundwater always contains dissolved bicarbonate. Complications may arise if the carbon-14 which enters from the atmosphere exchanges with carbon in limestone materials. This would give an apparent age far greater than the age of the water because the limestone is normally millions of years old and already free of carbon-14. This difficulty can be overcome, however, if the degree of exchange is known. It has also been suggested that natural radioactivity in the ground from isotopes of the uranium series could be used to measure groundwater age since the ratio between neighbouring elements in this family will depend on the rate with which groundwater is replaced.

Other Uses of Isotopes

Silt and sand transport by rivers can interfere with the utilization of water by filling up dams and irrigation canals. It is practically impossible to measure by conventional means the rate of transport of these sediments, a large proportion of which are carried along the bottom as so-called bed load. The possibility of using sand labelled with radioisotopes for this purpose has been investigated recently and may provide the answer. The Agency is sponsoring research on this method. It is also actively engaged in a study of the bed load transport in a tributary of the Mekong River in South East Asia.

All of the foregoing has concerned the use of radioisotopes in hydrology. It may also be possible to use stable isotopes in hydrological research. For example, oxygen-18 and deuterium seem to be promising in the identification of waters, as the proportions of various isotopes contained in rain vary with the altitude at which the rain hits the ground. Consequently, these two isotopes are being analyzed in the worldwide survey of precipitation mentioned earlier.

RESEARCH APPLICATIONS OF CALCIUM-47

Calcium, one of the most common elements on earth, is also one of the main components of human bone. Nevertheless, we still know very little about calcium metabolism; we know little about the accretion of calcium into and release from healthy bones; we know that the dynamics of calcium metabolism are affected by a variety of bone diseases such as rickets, osteomalacia and Paget's disease as well as by a number of endocrinological disorders such as hyper- and hypothyroidism and hyperparathyroidism, but we have insufficient knowledge of these pathological processes. A more detailed insight in the dynamics of calcium metabolism as affected by disease would allow a better understanding of the underlying disturbance and perhaps a more accurate diagnosis at earlier stages of its development. Furthermore, one of the effects of certain bone lesions such as fractures or malignant tumours is an increased accumulation of calcium in the lesion; in the case of tumours the early detection of such accumulation would render therapeutic measures possible at a stage when they are likely to be more effective.

Finally, because of the similarity of the bone-seeking qualities of both calcium and strontium, and in particular of the radioactive isotope strontium-90, a dangerous fission product, a better understanding of calcium metabolism is an essential prerequisite for further improvements of health and safety measures against radiation hazards.

A radioactive isotope that would enable us to widen our knowledge of the rates of calcium absorption from the gut, its distribution within the body, and its accretion into and release from bone and ultimate excretion seemed an ideal tool for these different lines of research.

Such a radioisotope, calcium-45, has in fact been in use for a number of years in animal experiments. It is, however, less suitable for human studies because of its long half-life of about 150 days resulting in a radiation dose which may exceed that generally thought permissible in man.

At the Third International Symposium on Radioisotopes in Clinical Medicine and Research held in Bad Gastein, Austria, in January 1958, the possibility of using the isotope calcium-47 for this type of investigation was discussed. It seemed particularly suited for this purpose since it has a half-life of only 4.7 days; it is, moreover, a strong gamma-emitter which permits easy detection of very small quantities from outside the body. It was, however, produced on an experimental basis only and at a price of US $1400 per mC* which was beyond the financial possibilities of almost any medical research institution or hospital. In view of IAEA's mandate to promote isotope research in the fields of radiobiology and medicine the participants asked the Agency to carry out a programme of encouraging research that might lead to cheaper methods of producing this isotope and of assisting in its practical applications in diagnosis and clinical research. The Agency took up this suggestion and the way it has pursued the project might be considered characteristic of its methods of dealing with such problems on an international scale.

As a first step, a small group of consultants convened by the Agency met in Vienna in December 1958 to discuss methods of calcium-47 production. Of the various processes reviewed (irradiation of calcium-46, calcium-48 or titanium-50) neutron irradiation of enriched calcium-46 in a nuclear reactor was considered to be the most promising method. But since the almost prohibitive cost of enriching calcium-46 constituted the main obstacle to obtaining this product at a reasonable price, the consultants recommended that research should first be directed towards finding improved production methods of calcium-46. Electro-migration was thought to be the most promising approach. An additional question was whether potential producers could be convinced that the demand for this isotope would be sufficient to justify the considerable investment required for a regular production.

To clarify this point, the Agency began by sending a circular letter to all its Member States asking them to indicate those institutions which might be interested in using calcium-47 in their research projects. Answers were received from sixteen Member

* mC = *Millicurie, a thousandth of a curie.*

Curie = the unit of radioactivity = 3.7×10^{10} *disintegrations per second.*