Future Trends in the Application of Isotopes and Radiation

by Hellmut Glubrecht

For some three decades, isotopes have found steadily increasing application in our scientific-technical world. The extent and the variability of these applications are probably not known to the majority of the people. Actually there are only few areas in scientific research, agriculture, medicine and industrial production which have not benefitted in one way or another from these modern and versatile tools of science and technology. Only modern electronics and data processing may have had a comparably widespread influence on technology.

The use of ionizing radiation is closely linked to radioactive isotopes, the most reliable, cheapest and energy-saving sources of this type of radiation. Ionizing radiation from electronic sources in the form of X-rays had been applied some twenty to thirty years earlier. Powerful radioactive sources with activities in the kilocurie range only became available after they could be produced in nuclear research reactors, i.e., in the late 1950's.

Meanwhile many applications of isotopes and radiation became routine. But the potential of this part of nuclear technology has by far not been exhausted yet. Some expected trends in their future development and application will be described here. New trends both in methodology and in fields of application can be foreseen.

GENERAL TRENDS IN ISOTOPE AND RADIATION METHODOLOGY

The unique feature of isotope application is the possibility to distinguish between atoms of the same element, but which have different origin and pathways within a complex system. Another outstanding feature is the extremely high sensitivity of detection methods. Both characteristics are ideally combined when radioactive isotopes are applied as tracers. There is no doubt that radioactive isotopes as tracers will be used in increasing amounts, especially as radioisotopes produced by proton bombardement in cyclotrons become more available.

On the other hand, there is an growing trend in the use of rare stable isotopes such as ^{13}C, ^{15}N, ^{18}O, ^{34}S, ^{48}Ca, ^{58}Fe, etc. as tracers. Stable isotopes have the advantage of not affecting the labelled samples (especially biological samples) or the environment by radiation. Moreover, there are no time limits to their effective use because of radioactive decay. They have, however, been rather expensive; furthermore, detection methods, like mass spectrometer or optical devices, were either costly or not very accurate. These drawbacks are now being overcome and the sensitivity of detection has already reached far below the parts-per-million level.

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Another method for measuring rare stable isotopes is based on Nuclear Activation Analysis (NAA) which often has the advantage of being non-destructive. In a number of applications the tracer is used only for localizing objects like dust particles, micro-organisms, plant pollen, insects or even fish. If the labelled sample will not be exposed to chemical processes, any "activable tracer" can be used, i.e., any rare chemical element like Dy, Eu, In, La or other will serve as a tracer and can be detected by NAA. This "Indicator Activation Method" may have good prospects in the future. It is likely to find broadest application in environmental research. Strong neutron sources for activation are now available in the form of research reactors throughout the world.

Another important development has been in the measurement of natural or environmental isotope ratios. This began in the field of isotope hydrology. The information which can be obtained by observing the sometimes very small relative changes in the concentrations or ratios in the isotopic composition of an element is remarkable not only in hydrology but also in such other areas as mineral prospecting or ecology. It seems that we are just at the beginning of the development of a new discipline which makes use of an extremely sensitive indicator for physico-chemical processes offered to us by nature.

Another important trend in methodology can be seen in the use of ionizing radiation both for analysis and for processing. Radiation analysis found its early application in medical diagnosis. It was then expanded to non-destructive material testing, to soil density and moisture measurements and to certain biological problems. Even medical applications have recently undergone a new development by introduction of computer-aided tomography. Gauges to be used in industrial processes will be simplified and improved. Neutron interaction with matter will find increasing practical application especially if ^{252}Cf sources will continue to be available. Agriculture is just starting to make use of scanning methods to determine biomass and plant structure.

Chemical analysis by radiation can be performed with NAA and Energy Dispersive X-Ray Fluorescence Techniques (EDXRF). NAA has mostly been confined to thermal neutron irradiation. But considerable unexploited potential lies in the use of fast neutrons, charged particles and high energy gamma-rays (produced by accelerators) for activation, as well as the application of prompt radiation for detection. EDXRF has proved its capability in recent years by using proton excitation rather than X-rays or electrons. It will no doubt become a complementary method to NAA and a strong competitor to chemical analytical methods.

Radiation processing is now finding a place in large-scale industrial applications. Its distinguishing features are energy saving and great homogeneity of effects which make it superior in most cases to heat treatment. Radiation sterilization of medical products is an established process. Food preservation by irradiation is now coming into the foreground. Intensive research on interaction of radiation with macromolecules will most probably open new horizons for improving various qualities of industrial materials. Another prospect is sewage treatment by irradiation.

New and unexpectedly useful effects of ionizing radiation may be found in the future. One example is the recent finding of favourable influence of rather low-radiation doses on differentiation of plants grown by tissue cultures. If the results obtained up to now prove to be reliable, this approach might open a new era in plant breeding.

APPLICATIONS IN AGRICULTURE

Although isotope and radiation techniques are already extensively exploited in the field of agriculture, their application in this field may yet exhibit the greatest expansion in the future. One reason is that agricultural production is still strongly bound to traditional methods; on the other hand, agriculture deals with extremely complex systems with many components that are yet unexplored.

The increased use of stable isotopes, which has already contributed vitally to our present knowledge of nucleic acid and protein metabolism, has special importance for research on the role of elements like C, N, O and S. ^{15}N will continue to be of utmost importance also for solving new problems and in special cases it might be supplemented by the short-lived radioactive isotope ^{13}N. One of the most challenging tasks in agriculture is the induction of dinitrogen uptake from air by non-leguminous plants. The conventional acetylene reduction method cannot furnish the integrated measure of total dinitrogen fixed over a plant's growing season. Measurements of this can only be performed by using N-isotopes.

Stable-isotope-labelled compounds can also be applied in field studies on the fate and metabolic processes of pesticide residues, as well as in long-lasting experiments on animal nutrition.

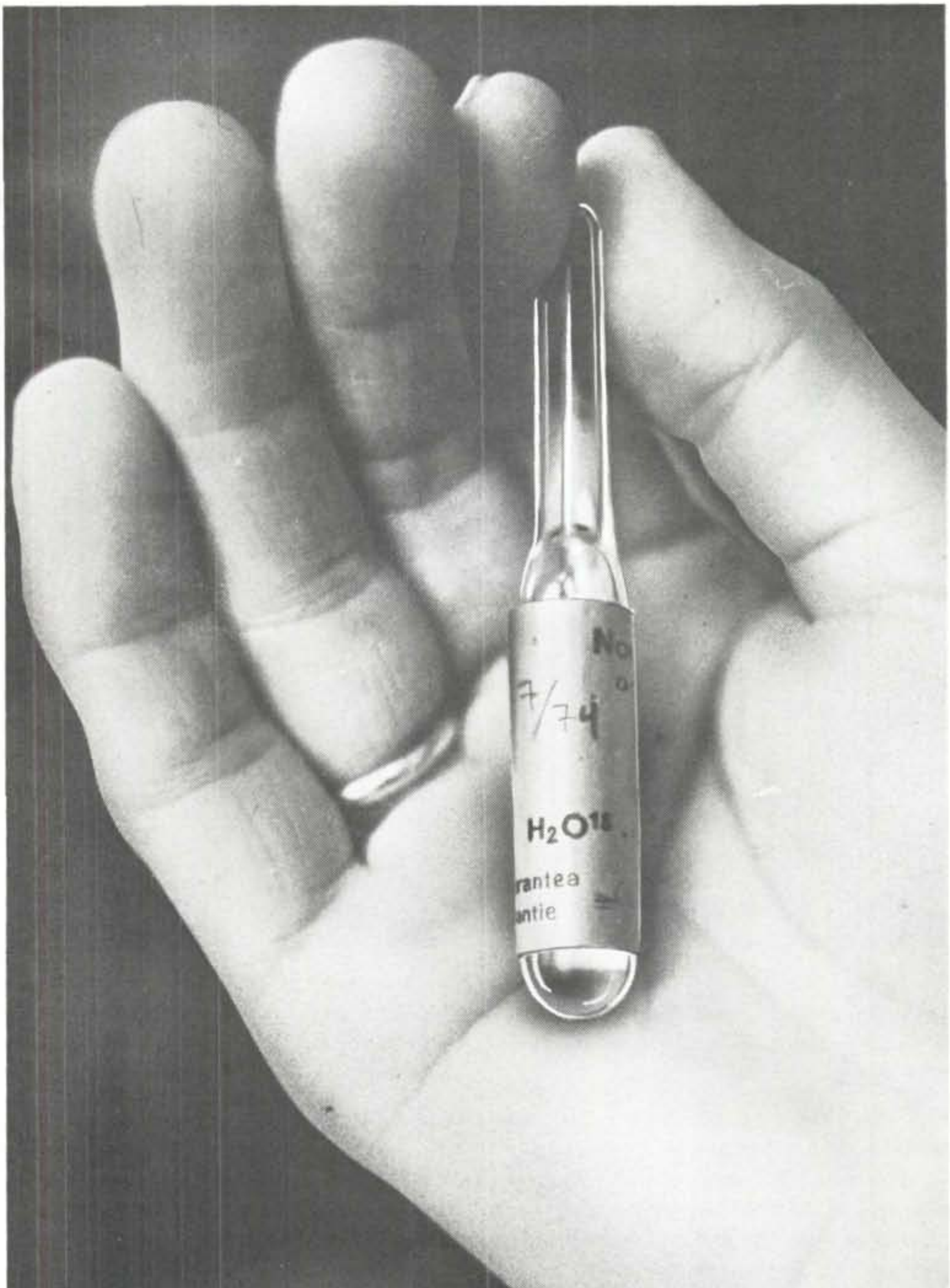
Radioactive isotopes will continue to play a predominant role in trace element investigations, especially studies on the interaction and synergism of various trace elements in soil, plants and animals. The use of radioactive-labelled substrates and reagents will also become indispensible in enzyme research. This is already being done in animal physiology where radioimmunoassay techniques are being used, but it could be applied with great advantage in food and soil contamination monitoring.

Isotope ratio measurements are just being introduced into agricultural research, e.g., $^{18}O/^{16}O$ for respiration control. A study of the isotopic composition of lead contaminants in agriculture indicated that the contamination was due to automobile exhaust rather than from lead naturally present in the local environment. The future will no doubt bring numerous other applications of this very efficient method.

Of the many other applications of isotopes in agriculture which might develop further, one item should be mentioned: the importance of non-radioactive labelling in ecology. Insect control has to be based on profound knowledge of the migration and behaviour of the animals. Activable tracers, as mentioned earlier, offer an ideal means for field studies of this type and they will certainly come more and more into use. It is also to be hoped that the fascinating results in fish ecology which have been achieved by labelling of salmon with europium, samarium and dysprosium will encourage fishery experts to continue on this line.

An example of advanced radiation analysis is a scanning method that permits measurement of biomass distribution along cereal plants during all stages of development. Further experiments may be used to check the influence of various fertilizer treatments and of climatic changes. Similar scanning methods are developed in forestry to detect areas of disease in tree trunks.

One of the first practical applications of radioactive isotopes was as tracers in chemical and biological processes. Today there is a growing trend in the use of rare stable (non-radioactive) isotopes as tracers. Shown here is a sample of water containing the stable isotope oxygen-18 instead of the more common isotope oxygen-16. Photo: Norsk Hydro.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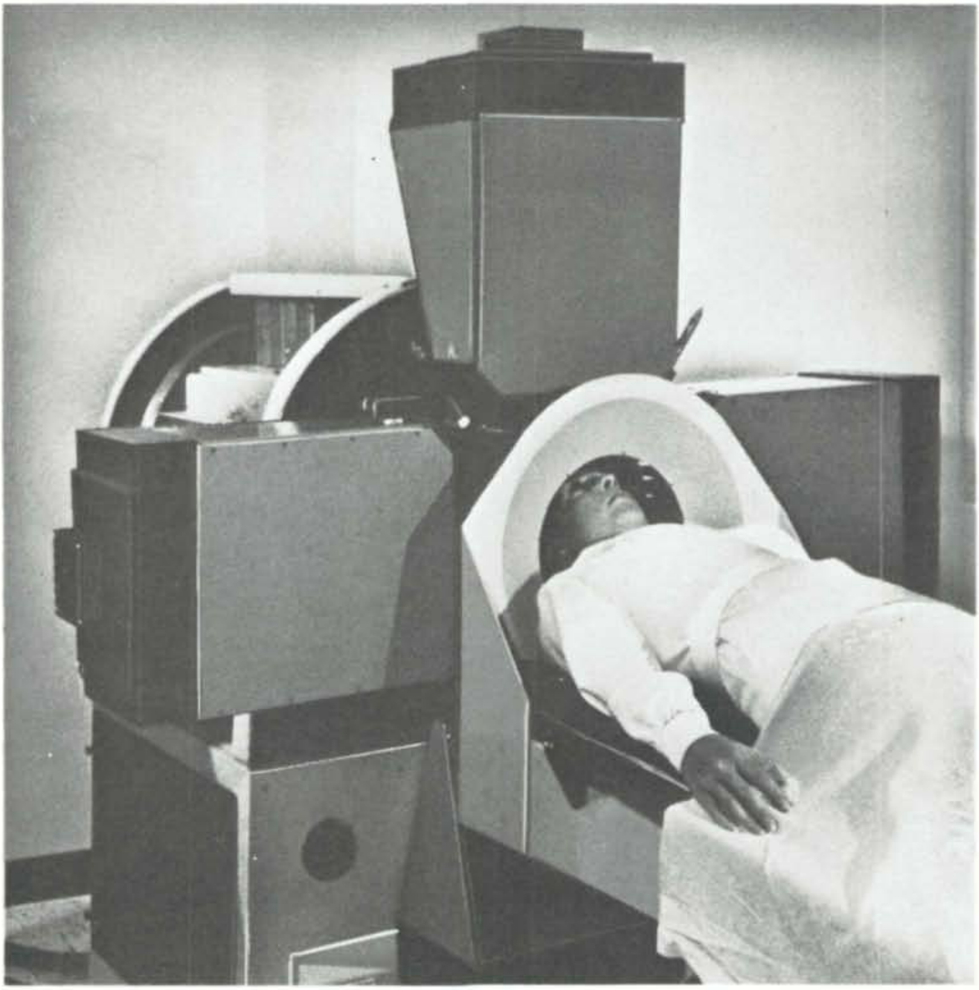
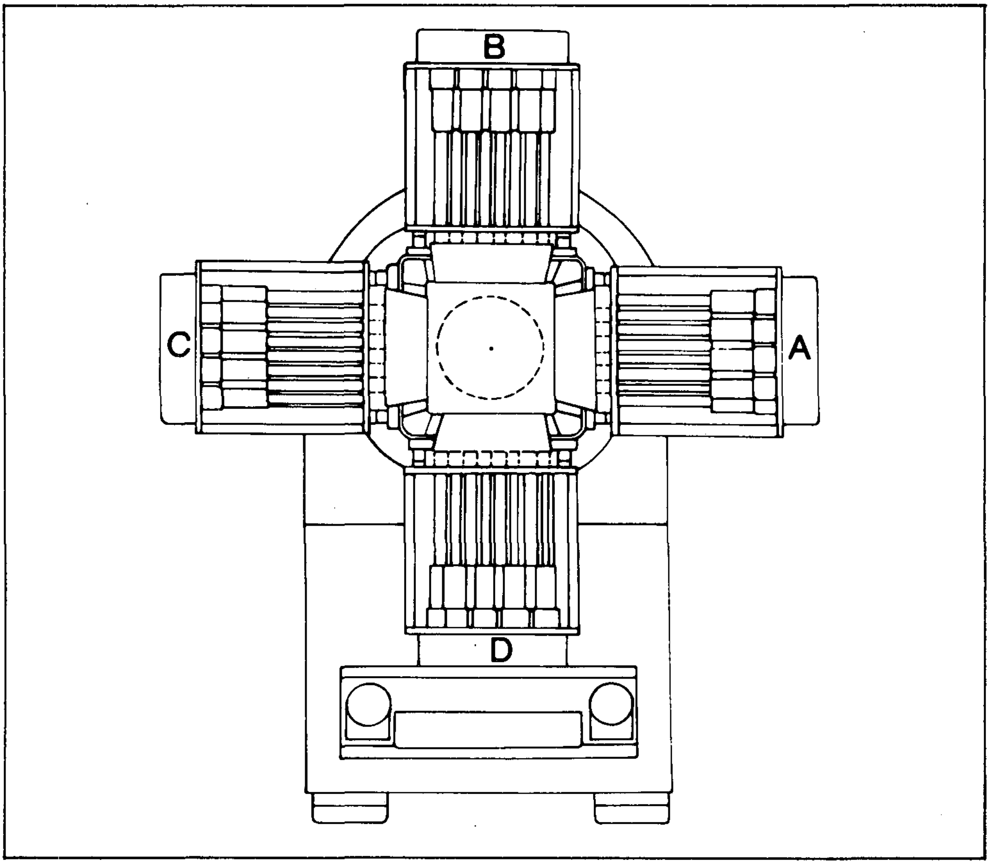


Radiation analysis is also most suitable in monitoring diurnal variations in water conservation in plants as well as in soils, and this will be of utmost importance for the development of dry farming.

The most important application of radiation processing in agriculture is food preservation by irradiation. This method is now under final consideration by the Codex Alimentarius Committee of FAO and WHO for a number of food items. Future work will concentrate on obtaining evidence of wholesomeness for other food items. But these studies will be of a more basic character and deal with radiation effects on general food components to prove that food irradiation as a general process is acceptable up to a certain dose level. More effort will centre on practical large-scale studies of technological and economic feasibility. An integrated preservation system combining heat treatment and irradiation will be investigated.

Irradiation of garbage for making this waste material available for animal food is another promising approach. Sewage treatment by radiation may lead to increased production of a fertilizer material rich in organic matter.

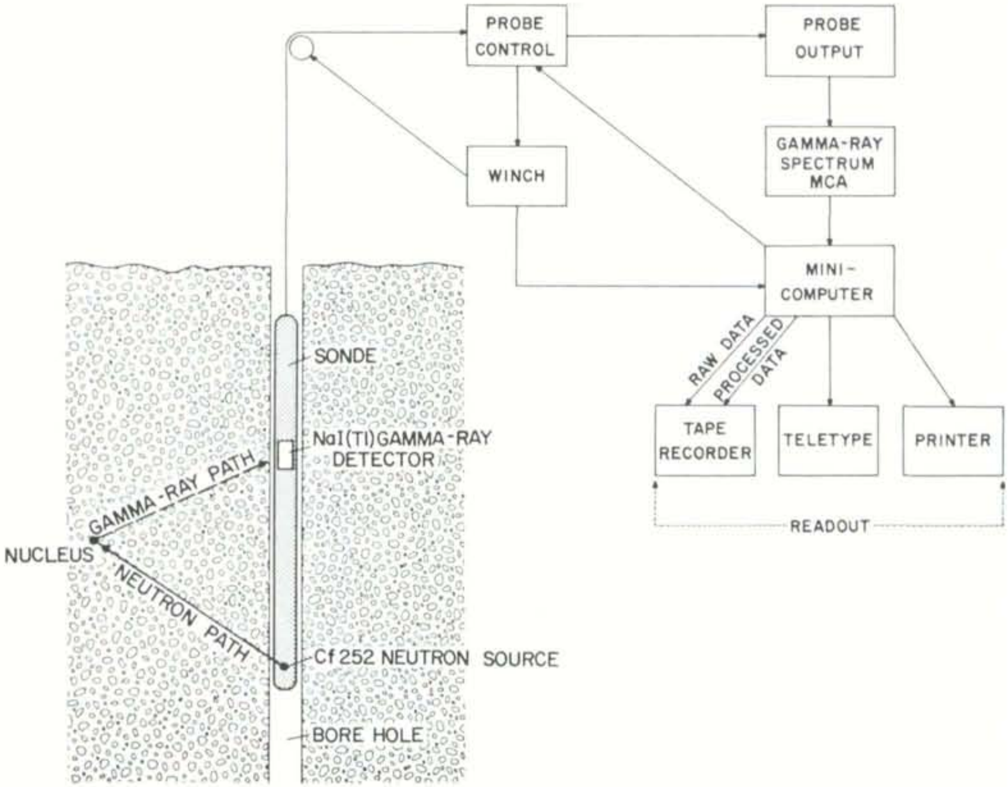


Radionuclide computed tomography system at The Center for Health Sciences, University of California, Los Angeles, is used to study blood flow in the brain and cerebral glucose metabolism. The reconstructed image, or tomogram, is a cross-section of the brain and a series of tomograms along different planes can provide a three-dimensional image of the brain. The system consists of four detector assemblies. Radionuclides used in conjunction with the system include ^{99m}Tc, ^{123}I, ^{111}In and ^{18}F.

Two areas of radiation application in agriculture may expect some progress from the use of neutron irradiation instead of gamma rays: plant breeding and the sterile insect technique (SIT). The advantage of sterilizing male insects by neutrons instead of gamma rays has become apparent with tsetse flies, which suffer less physiological harm when exposed to moderate neutron doses and, though sterile, remain fully competitive with wild tsetse fly males.

MEDICAL APPLICATIONS

Nuclear medicine is now developed to a high standard in most industrialized countries. The instrumentation used is rather sophisticated and expensive. The advantages of nuclear medical diagnosis as compared to conventional diagnostic methods are tremendous as far as information content is concerned. Another advantage is a reduction of inconveniences for the patient. In view of these consideration, it would be highly desirable to simplify nuclear medical equipment and to adapt it to working conditions in tropical or subtropical developing countries. This is a major programme component of the IAEA at present.



Borehole logging of the grade of nickel or copper deposits can be accomplished by measurement of prompt gamma emissions induced by neutron capture. A neutron source is lowered into a borehole and the resulting gamma emissions are measured by a scintillator. Such nuclear techniques permit the characterization of larger and more representative samples than is generally attained by conventional coring techniques.

But there are also considerable further developments to be expected in the medical field. *In vivo* radionuclide imaging, if done by scanning, can only inform on local distribution of a radioactive-labelled pharmaceutical. Dynamic studies of function and physiologic processes have to be performed by using gamma-cameras which combine spatial localization with time variation. Gamma-cameras have already reached good resolution power, but could be further improved.

Short-lived radioisotopes, including cyclotron-produced positron emitters, are becoming more available, and the list of industrially manufactured radiopharmaceuticals is increasing. A most important development is tomographic imaging with positron emitters using annihilation gamma radiation.

One of the most successful methods in clinical medicine and biomedical research is radioimmunoassay (RIA). It is highly specific, at least if double-antibody techniques are applied. It has reached the picogram level of sensitivity. Accuracy ranges from ∓ 10%

down to ∓ 2%, but could certainly be improved in the future, preferably by automatic sample preparation. Today, more than 80 kinds of RIA have been developed, this figure will undoubtedly increase. Some 100 million RIA tests were performed in 1975 throughout the world, and it is estimated that the number of tests will go up to 250 million by 1980.

Monitoring of the concentration of certain elements in human body samples has been done up to now mainly for studying deficiencies caused by nutrition. It is increasingly recognized that measurement of elemental composition of such samples also has a high diagnostic value for large-scale screening of infectious and non-infectious deseases. This will lead to model studies with radioactive and, even better, with stable isotopes, and also to comprehensive use of NAA and EDXRF in medicine.

INDUSTRIAL APPLICATIONS

Tracer studies and control of industrial processes have been undertaken frequently, e.g. oil transport, wear measurement, etc., but not to that extent as in biological systems. The less complex character of industrial processes more often allows the application of conventional methods.

Strong increase is to be foreseen in the application of gauges and other radiation analytical methods. Promising techniques in the petrol industry are the quantitative determination of hydrocarbon saturation by the use of pulsed-neutron capture logs and logs based on measurements of gamma rays from inelastic neutron scattering. If such techniques are combined with a density gauge, hydrocarbons can be detected up to tens of meters distant from the borehole.

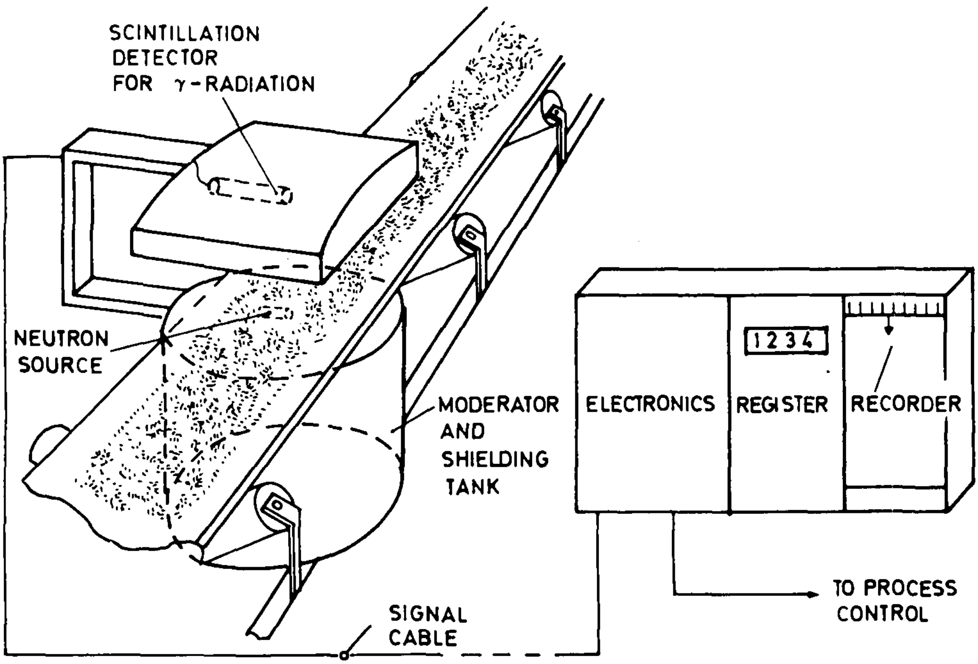
Mineral exploration and mining may strongly profit from the development of portable EDXRF instruments using isotopic sources and high resolution Si(Li) detectors. Such instruments will allow simultaneous multi-element analysis of soil and stream sediment samples in the field during geochemical survey.

An important trend in the use of nuclear gauges in the mineral processing industry will be the development of devices for continuous on-stream and on-line measurement of density, mass flow, moisture content and element concentration. The equipment developed for static measurements has already been somewhat adapted for on-stream measurements, but it could be considerably improved. The same holds for nuclear techniques to continuously determine particle size distribution in an industrial process.

In basic studies of process dynamics, tracer techniques may play an increasing role, particularly in the optimization of low-grade ore exploitation.

Ionizing radiation can produce cross-linking and grafting in plastic and rubber. It is to be expected that more attention will be paid to these energy-saving processes in the future. In cellulose industry, developments are on the way to prepare fire-retardent fabrics and new classes of non-leachable wood preservatives by use of gamma or electron radiation.

The radiation sterilization of municipal waste waters for safe disposal and possible use in agriculture has already been mentioned. Another application now developed is to preserve antiques and old documents based on radiation-induced wood-plastic combination.



Measurement of gamma radiation induced by neutron capture provides a means for on-line determination of the iron content of ore concentrates.

HYDROLOGY AND ENVIRONMENTAL CONTROL

The use of "natural" isotope measurements (^{14}C, ^{3}H) and of isotope ratios ($^{2}H/^{1}H$, $^{18}O/^{16}O$) has probably reached the highest level of sophistication in its application to problems associated with the assessment of water resources. We can expect an increasing use of these methods as more groups in the developing countries acquire the ability to make the necessary analysis and apply the techniques.

Moreover, the combined applications of environmental isotope measurements and chemical data is expected to increase, particularly in studies on the mechanisms of salinization of waters and on the problems of pollution. The latter will no doubt see an increase in the use of measurements of ^{34}S and ^{15}N.

The world-wide energy problem has prompted a new assessment of the potential of geothermal sources of energy. Environmental isotopes are being used in the hydrological study of geothermal systems, for example, in the evaluation of recharge areas, mixing phenomena between different fluids and mixing times. Estimation of temperature of the reservoir is a key parameter and, in this regard, isotopic geothermometers are expected to play an increasing role in future.

The use of "artificial" isotopes in surface water measurements as well as in the "bore-hole techniques" (to determine groundwater velocity) may be enhanced by the use of activable tracers. Such tracers are harmless to the environment and can be used for large-scale field experiments. A new technique which might be especially profitable in sediment studies is the combination of small amounts of radioactive tracers, for a first qualitative evaluation, with larger amounts of an activable tracer for quantitative long-term evaluation.

It is difficult to imagine carrying out environmental control and monitoring without making use of nuclear methods. NAA and EDXRF allow fast screening of more than 30 elements of importance in environmental pollution control. The free capacity of research reactors and accelerator time which is now available in many nuclear centres make a world-wide programme of such measurements possible and desirable.

Propagation of gaseous or aerosol pollutants can easily be monitored by special stable isotope combinations or by activable tracers. A large-scale experiment in USA used methane of the composition $^{13}C_2H_4$, which moves easily with air and can be detected by special mass spectrometry. Detection was achieved over distances of more than 1000 miles.

Dysprosium-labelled aerosols can be produced by pyrotechnic reactions and easily distributed as local sources in the atmosphere to study pollution behaviour under different climatic conditions. Exhaust and dust pollution originating from industrial plants may also be monitored by labelling with activable tracers.

CONCLUSION

Future trends can be described by extrapolating from the present situation. Although the trends discussed in this paper may change slightly and the list of topics dealt with is incomplete, it should be clear that isotopes and radiation have an increasingly wide field of application in our technical world and strong future developments are to be expected.