Nuclear science and technology in developing countries: Potential and perspectives

Reflections on nuclear energy's development in energy, agriculture, medicine, industry, science, and other fields

by Noramly bin Muslim

Over the past 30 years of the IAEA's existence, developing countries have pursued virtually all areas of nuclear science and technology, leading to a broad-based development of atoms for peace around the world. Expectedly, progress has been achieved not without problems and faster in some fields than in others. Many complex facets are linked to nuclear energy's peaceful development. Given the record, what is the potential? A review of some main fields and applications in which the IAEA is involved through technical co-operation projects and other activities may offer some perspectives.

Nuclear power plants

If during the last few decades the peaceful applications of isotopes and radiation have advanced more rapidly in developing countries than the means of nuclear power production, the reasons are undoubtedly linked to time and money. Nuclear power involves considerable financial investments and requires a substantial infrastructure. And in the field of energy, a long-term forecast is perhaps more necessary than in many other sectors. That kind of forecast is complex and difficult because it has to integrate a policy involving other energy sources, as well as a number of factors associated with the national economy and with support industries — such as the capability of guaranteeing the operational maintenance of the equipment — or outside factors, such as the price of uranium or oil. A forecasting error may have grave consequences because the response time of the "systems" involved is long; for example, an average of roughly 10 years is needed for a nuclear power programme to begin to take proper shape.

The first important step for a developing country is the preparation of a sound and widely supported national development plan. With such a plan, and only with such a plan, can the effective development of human resources and industrial infrastructure be ensured. This will open the door to all non-power applications. These, as pointed out later, are of obvious interest in all areas of economic activity as well as in health, while paving the way for the consideration of nuclear power if national conditions warrant.

In the energy sector, the difficulties entailed in feasibility studies before the decision to launch a nuclear power project are extensive. It should be added that these studies can only be carried out by energy experts from the groups involved, but in this area, perhaps more than in others, assistance from outside is absolutely necessary. Many other factors also must be weighed. These include the political will of the government involved to carry through with such a long-term,

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Photos above (left and right): In 1977, the IAEA and the Food and Agriculture Organization jointly sponsored a one-month course on plant breeding at the Indian Agricultural Research Institute in New Delhi. Twenty scientists, including those from Indonesia and Ghana shown here, participated. (Credit: A. Micke, IAEA)

complex project; the public understanding and acceptability of nuclear power; the national industrial capability to build, operate, and maintain such a project; and, certainly not least, the availability of adequate financing on terms that make such a project economically as well as technically feasible. Then there are the other obvious vital subjects to consider on the technical aspects of nuclear power: namely, safety and radiation protection, the fuel cycle, waste storage, and decommissioning, among others.

Given all these factors, what are the prospects for the development of nuclear power in developing countries?

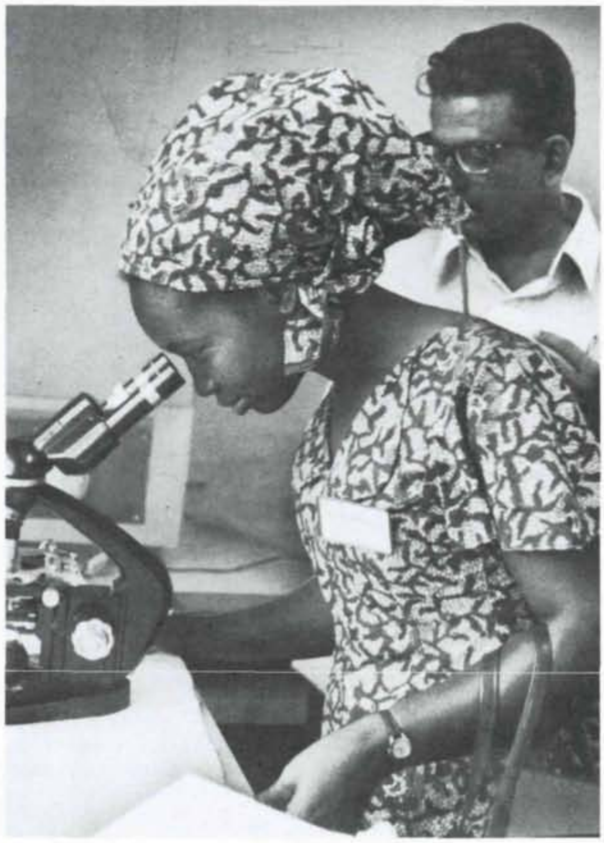
Generally speaking, since energy consumption is a reflection of a country's development, one can predict that energy consumption will have to increase in the future; in this respect, it is interesting to note that electricity consumption is growing faster in developing countries than in industrialized countries. The vital question is then, at what rate.

The introduction of nuclear electric power has been slower than anticipated in developing countries: As of 31 October 1986, there were 21 nuclear units in operation. Another 18 units were under construction, nine of them in only two countries, namely India and the Republic of Korea. The others are in Argentina, Brazil, China, Cuba, Iran, Mexico, and the Philippines.

Considering reactors known to be connected to the grid and those under construction, the estimated growth of nuclear power capacity in developing countries up to 1990 is around 12.7 gigawatts-electric (GWe), which represents 10% of the estimated growth for all countries (120.5 GWe). For the more remote future, low IAEA estimates of nuclear power generating capacity would be (excluding developing countries with centrally planned economies in Europe) 30 GWe and 40 GWe in 1995 and 2000, respectively. This would represent (for both estimates) 4% of the total capacity.

Such forecasts should be considered only as rough estimates, since they involve unpredictable factors or developments — for example, possible re-examination of national plans following the Chernobyl accident, or the introduction of small- and medium-size power reactors for which economic assessments are in progress.

Among developing countries, the Republic of Korea has one of the most active nuclear power programmes. Shown here are models for the design of turbine halls at two of the nuclear units under construction in the country. (Credit: French Nuclear Newsletter, 1986)



Food and agriculture

Nuclear techniques have become essential tools for use in research and development in the food and agriculture sector. These techniques are used mainly for the optimization of animal nutrition or the use of fertilizers, the creation of new varieties of plants or more effective and less harmful pesticides, the eradication of harmful insects, and the preservation of foodstuffs. Developing countries have not been slow in showing interest in these techniques and in using them profitably. More often than not they are developing these techniques with the help of the joint division of the IAEA and Food and Agriculture Organization (FAO), which was set up in 1964. They are benefitting from approximately 150 technical co-operation projects.

• ***Animal nutrition.*** In many countries, particularly in tropical or sub-tropical regions, the shortage of meat and milk is mainly a result of poor productivity rather than insufficient livestock. Radioactive tracers can be used to study the processes of fermentation, the utilization of protein in the rumen, and assimilation processes in the intestine. Thus, they make it possible to select inexpensive nutrients, such as straw, thereby helping to increase

In animal research, radioisotopes typically are injected to serve as tracers in studies. Over the past 30 years, IAEA-supported projects have focused on animal health, nutrition, productivity, and other areas.

animal weight and milk production. These gains may also result from better reproductive management of these animals; for this purpose, radioimmunoassay (RIA) techniques are used to determine the numerous factors involved. Both RIA and tracer techniques are also being used successfully to control animal diseases.

● ***Pesticides and fertilizers.*** In agriculture, the intensification of crop growing in developing countries is being accompanied by a substantial increase in the use of insecticides; the use of fertilizers will take the same path. Generally speaking, the use of fertilizers, insecticides, and herbicides has a beneficial effect, but they also have an effect that is often harmful because such products (or by-products) are carried into the ground and surface waters. Instances of eutrophication of lakes caused by fertilizers leached from crop soils are well known. Optimization of the utilization of these substances calls for knowledge of the transport phenomena and effects of interaction with the environment to which they are exposed after they have been applied. Tracer techniques are the preferred approach to carrying out such studies successfully. One can, for example, determine to what extent the rate of insecticide loss depends on temperature, precipitation, sunshine, and the type of soil and crop.

● ***Mutagenesis and seed selection.*** Another important nuclear technique applied to help increase food production is seed irradiation, using gamma radiation or fast neutrons to induce mutations. The genetic diversity from which species are selected is thereby enlarged and, when combined, they are able to produce varieties with the desired properties. These include better yield, resistance to unfavourable external conditions, salt water tolerance, and greater resistance to diseases. As one might guess, this technique is of interest to a large number of developing countries. The IAEA has a very active programme in this field and supports some 20 technical co-operation projects. The Agency has stressed the value of these techniques for developing countries and many of them are now in active use in the developing world. These applications will continue to expand since they address vital concerns and are quite well accepted by the public. The exact rate of their growth depends on specific conditions in each country, especially economic ones.

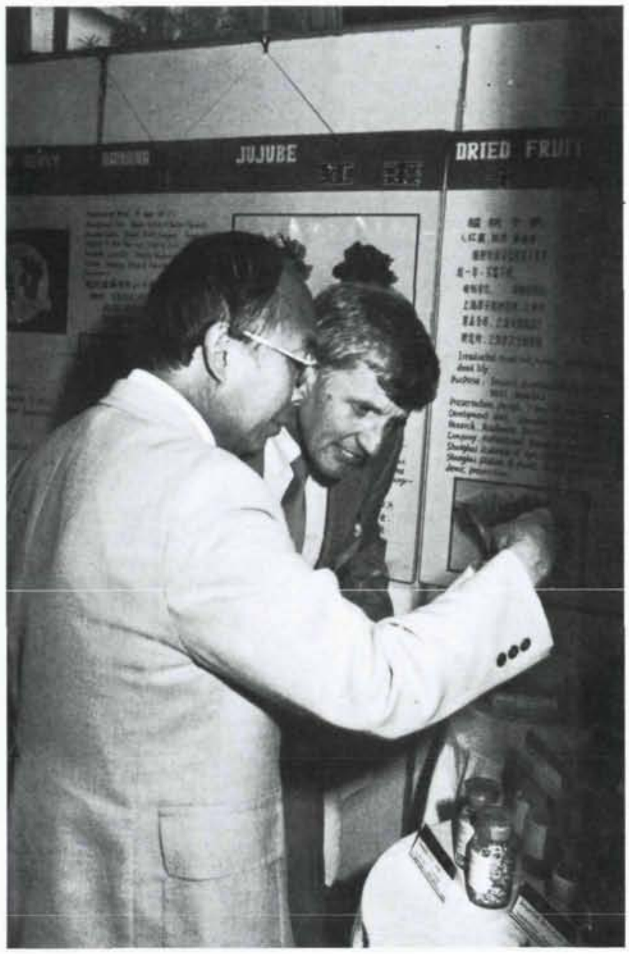
● ***Food irradiation.*** Preservation of food by irradiation is a well-proven technique. It inhibits the germination of vegetables, prolongs their shelf-life, controls pathogenic agents, parasites, and insects that attack foodstuffs, and ensures microbial sterilization of spices and dried ingredients. It is of prime interest to developing countries, especially those in tropical regions, for preserving food products and ensuring disinfection of spices. Some of these countries, as well as a number of industrialized ones, have approved the irradiation of many products. The conclusions reached in 1981 under an international food irradiation project, which stated that products irradiated at a total average dose below 10 kilogray were safe, and the adoption by the Codex Alimentarius Commission in 1983 of standards for irradiated food, are likely to encourage progress in the use of the technique. Over the last 3 years, we have seen in the Agency's technical co-operation programme a rising interest among developing Member States in the application of this technology; this is a trend that is firmly under way. The issue of public understanding and acceptability of food irradiation is the major obstacle to its rapid expansion. There is now a general recognition of the widespread requirement for greater effort to be made to gain the public's acceptance of the many significant benefits that food irradiation offers.

Industry and earth sciences

Some applications of nuclear techniques in the area of industry and the earth sciences were among the first to be developed and have now become established as conventional practices often implemented on a commercial basis.

● ***Thickness, density, and level gauges.*** Almost all large paper-making machines are equipped with nuclear gauges providing continuous information on the surface density of the paper which is being manufactured; almost all the major steel mills are equipped with nuclear thickness gauges. In addition, level gauges are used for industrial processes in the thousands. These devices are no longer the subject of research and development except in the case of very specific problems. Their introduction into the developing countries is slowly following the industrialization process. It should be noted that the Regional Co-operation Project (RCA) of the IAEA and United Nations Development Programme

Two of the hundreds of participants at the joint FAO/IAEA seminar for Asia and the Pacific on food irradiation, held in Shangai in April 1986. The model is of the Shangai irradiation facility, which is now in operation.



(UNDP) is playing a very positive and stimulating role in introducing this type of equipment in the Asia-Pacific region, particularly as far as paper and steel gauges are concerned.

• ***Tracers in industry.*** The application of tracers in industry has developed rapidly since World War II. It provides a simple method of "trouble-shooting" in the manufacturing industry, solves various measurement problems and provides increasingly sophisticated solutions to problems of optimizing processes and control. For the latter, the tracer method owes its success to the fact that it is the only technique that can deal with the dispersion phenomenon. This phenomenon is of crucial importance in industrial processes in which it is exploited (mixers, chemical reactions) or where it is guarded against (transport of fluids in pipes). In many industrialized countries, this method is used on a commercial basis by service companies. In other countries it is only applied in the laboratory or on a pilot scale and the utilization of tracers in factories is licensed only with difficulty. A more liberal attitude will undoubtedly emerge here since process optimization is a constant preoccupation of industries and engineering companies and the tracer technique is often the only applicable one. The amount of radioactivity handled in in-plant tracer tests is always very low and these tests always involve very short-lived isotopes. Only a few developing countries are successfully using tracers in industry. There is reason to believe that this activity is likely to increase in developing countries: The cost of necessary infrastructures is negligible compared to benefits obtained, and it is bound to follow the process of industrialization.

• ***Non-destructive testing.*** Nuclear methods of non-destructive testing (NDT), essentially gamma radiography, are commonly used in most developing countries. Quality control of equipment is often a vital question and also a competitive factor. This is probably the main reason for their widespread use. Various activities at the international level with the IAEA's participation are designed to harmonize training methods for technicians concerned with NDT. One can expect this type of assay to increase still further in developing countries in the wake of progress in national manufacturing. It will no doubt do so in the longer run when, for some countries, quality control will be necessary at market level. A glimpse of the future in this sense is perhaps given us today by Singapore. There, a policy of purchasing "turn-key" factories is pursued and particular emphasis is placed on the development of quality-control methods for material intended for export.

The IAEA has helped many countries that are interested in using isotopes to study water supply problems. In Jamaica in the 1960s, the Agency carried out isotope studies for a project of the United Nations Development Programme.

• ***Radiation chemistry.*** The use of radiation as a source of energy for different industrial processes has gradually developed into a number of fully established applications. Starting in the early 1950s with industrial radiation sterilization of medical supplies, new applications came in as a result of extensive fundamental and applied radiation research. Radiation-induced modification of polymers was developed into successful industrial processes, especially in the wire and cable industry, packing industry, and others. Later, radiation curing covered a broad range of applications, substituting and complementing ultraviolet radiation processes or heat processes, for example. At present, some 150 high-capacity industrial sources of radiation (mainly cobalt-60 gamma sources) are used in about 45 countries for industrial uses. Several hundred electron-beam accelerators are in commercial use for different types of radiation crosslinking and curing.

New processes are being developed and they are expected to become commercial in the near future. Already mentioned has been radiation processing of food products for purposes of preservation. Others include radiation decontamination of waste products for safe re-utilization (sewage, sludge), radiation treatment of industrial flue gases for environmental protection, and different biomedical applications. Contrary to what is commonly believed, radiation processing is in many cases a more appropriate technology for developing countries than any competitive technology based on alternative energy sources. Industrial radiation sterilization is, for example, a simple and reliable process, safe for the environment and for the personnel handling radiation sources. Applied safety standards are the same in developing countries as in the most developed ones. The same cannot be said for competitive technologies based on the use of toxic gases, where high safety standards in advanced countries are never achieved in less-developed countries. The potential for radiation sterilization was recognized long ago by developing countries, many of them having non-industrial facilities for the process. The benefits are evident and the impact on general standards of health care is quite significant.

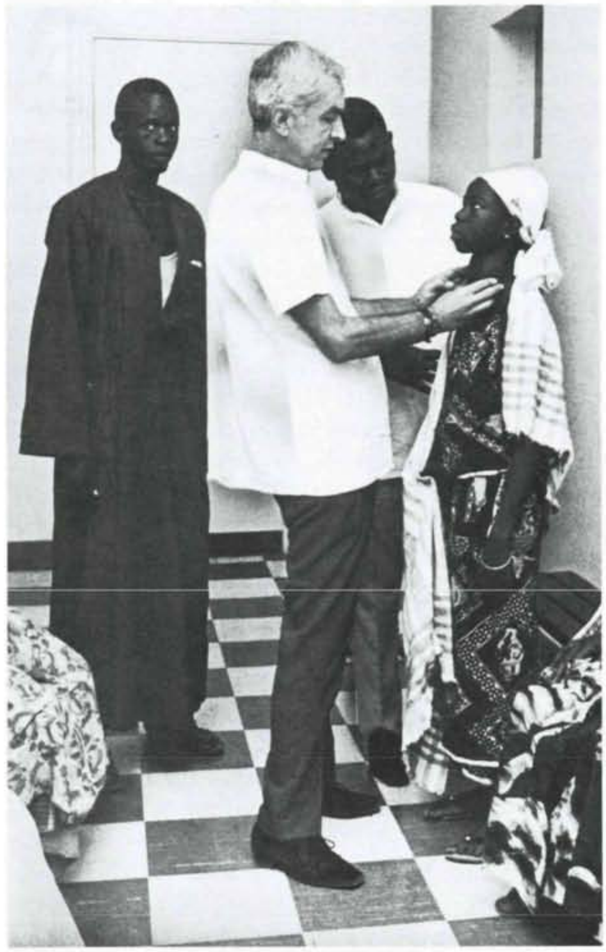
However, the benefits in other spheres of activity are not yet fully appreciated or utilized. One main reason may well be the status of national programmes in radiation sciences and technology: In radiation engineering, radiation physics, and chemistry, there is a lack of infrastructure, appropriate background, and relevant information. This makes it difficult to identify industrial opportunities and to prepare and execute industrially oriented radiation technology projects. It has been noted that those countries having relatively well-developed radiation research programmes were in a better position to apply the new technology at an earlier stage, and to carry out the transfer of this technology. More sophisticated technologies like radiation crosslinking and curing are being transferred very slowly. There are many difficulties involved, mainly due to the lack of a national research capability for quality control, process control, process development, material development, and so on. The potential for the industrial application of radiation has been identified in many developing countries and the need will definitely increase. Growth will be alongside general industrialization, and the growing necessity for better standards of health care, safety of personnel, and for new and better quality products, environmental conservation, and other reasons.

• ***Nuclear analytical techniques.*** Like all analytical techniques, these affect many branches of research and technology. Their applications are particularly important in industry and in the earth sciences. They include activation analysis by epithermal and fast neutrons, and various tracer techniques such as analysis by isotopic dilution, X-ray fluorescence induced by nuclear radiation and, by extension, X-ray fluorescence, regardless of the mode of excitation, although the basic phenomenon involved is not nuclear but atomic. These techniques are widely used in many analytical laboratories also dealing with non-nuclear methods. Activation analysis, in particular, is used in some ore prospecting sectors, geology, medicine, environmental monitoring, and industrial research. Many IAEA technical co-operation projects concern the introduction of these techniques in developing countries where a number of laboratories have been set up. These laboratories, when they involve activation analysis, are set up around nuclear research reactors or neutron generators. They usually provide the analytical support for research performed at nuclear research centres, as well as for other national organizations. X-ray fluorescence is not dependent on the availability of large facilities, such as a nuclear reactor or a particle accelerator; it is employed, for example, in prospecting and mining operations, in industry, and in various research institutes. An activation analysis laboratory is often planned in association with a research reactor to provide support for other activities that are not always determined beforehand. This may lead to development of an analytical method as an end in itself and not as a means for solving a specific type of problem. A risk of this kind can be avoided by paying careful attention to the needs of the end users of these techniques. One can predict that nuclear analytical techniques will continue to multiply in developing countries. These requirements are now well known in the most advanced countries and the role of nuclear techniques in relation to non-nuclear techniques is well understood. It seems that these needs exist in developing countries and have certainly not yet been fully explored.

• ***Isotope hydrology.*** It is commonplace to point out that water supply problems are crucial to developing countries. Nuclear techniques making use, first, of artificial tracers, then of environmental tracers such as deuterium, oxygen-18, tritium, carbon-14, and others, were among the first to be developed since 1950-55. Problems involve all stages of the water cycle, and the usefulness of these techniques for solving them is universally recognized, either as a complement to non-nuclear techniques or as a technique in itself. Natural labelling of water resources by stable isotopes of hydrogen and oxygen, or the radioactive decay of natural elements which they contain, are used to overcome difficult problems of relationships, mixtures, origin, and dating. The IAEA has played a major role in setting up isotope hydrology laboratories in many developing countries. There is a long way to go before problems of water resources in most developing countries are solved. That is why the activities of laboratories concerned continue to make headway and why other laboratories will come into existence. They will have to face new problems, such as water pollution, or have to contribute to exploitation of natural resources, such as geothermal resources, which until now have been unexploited.

Nuclear medicine

Radioactive tracers have been widely and fruitfully applied in the medical field. Such use is generally known as nuclear medicine. Some 60 developing countries now have programmes in this area. Tracers are used for



Back in 1967, the IAEA assisted a project in Senegal at the Radioisotope Laboratory at the West African Cancer Research Institute at Dantec Hospital in Dakar. Today, under other projects, the IAEA continues to assist Senegal in nuclear medicine fields. (Credit: UN)

diagnostic purposes and for treatment of diseases, as well as in medical research. There are four main categories of application classified according to the way in which the radiation is detected and the way the tracers are administered.

• The tracer is administered to the patient and the radiation is measured outside the patient. Nuclear imaging of body organs belongs to this category, for example brain scanning, as well as all tests designed to describe a physiological process, such as the excretion of a labelled molecule by the kidney.

• The tracer contained in a physiological liquid sample is measured *in vitro* to determine, for example, the blood volume or to study the absorption of vitamins.

• The patient does not receive any tracer and all tests are carried out *in vitro*; this is the case, let us say, of radioimmunoassay (RIA) hormone tests.

• This category concerns radioisotopic therapy, which includes the well-known treatment of cancer of the thyroid with radioactive iodine.

RIA, which makes it possible to study the body's system of defence against parasitic elements or to make diagnoses, has assumed considerable importance, particularly during the last decade; as a result of the very sensitive measurements of antigens or antibodies that it permits. Moreover nuclear imaging, which makes it possible to see labelled organs after the patient ingests a radioactive tracer, has undergone remarkable development during the last few years. It has gone from the first scanners to gamma cameras which, when connected to a computer, make possible what is today called tomography, or in other words, sectional images of body organs. These techniques and others involved in nuclear medicine call for highly specific radiopharmaceutical products for which there has to be very strict quality control. The preparation of these radiopharmaceuticals gives rise to a very active industry. The development of new radiopharmaceuticals, including quality control procedures and the required instrumentation, is carried out almost exclusively by the more advanced and well-endowed national and private or commercial laboratories in technology-oriented countries. With a few exceptions, laboratories in developing countries have not been part of this development. Incidentally, the development of new marketable radiopharmaceuticals is a lengthy and costly exercise, lasting in many cases several years and requiring considerable economic and human resources. However, the time lag from the moment a new product is successfully tested and approved for clinical use in a technological country and the time when a similar product is produced locally (usually at the national nuclear research centre of a developing country) is not as long as in many other areas. In some instances the lag is not more than a year. This is an example of the relatively smooth flow of information and know-how that has been put to better use, particularly in the more advanced developing countries. Of course, the situation is quite different in those less-advanced developing countries, which do not import radiopharmaceutical kits produced by only a few large commercial suppliers.

There is, however, another related area of nuclear medicine where very little technological transfer has occurred. This is the production and supply of radioisotopes and radioisotope generators of medical importance. The available generator technology of the radioisotope most widely used throughout the world in nuclear medicine, namely technetium-99m, is based on very costly and sophisticated radiochemical procedures involving the production of fission molybdenum-99, the parent radioisotope of metastable technetium-99m. Only a few of the most advanced industrialized countries produce technetium generators. Developing countries have found it extremely difficult to absorb and master this technology, both for economic reasons and through lack of nuclear reactors with appropriate neutron fluxes and processing facilities. Some countries import technetium-99m generators in considerable quantities, although they have nuclear research reactors in operation. Thanks to new concepts, an alternative generator technology is emerging now to facilitate the use of medium- to low-power research reactors. Some of these concepts have already been known for many years; however, there has not been much progress. Large commercial producers have not been, and are still not, interested in making advances in this technology. There is simply not enough economic incentive for this. Some developing countries, however, have realized that they would greatly benefit from these new technologies and have therefore started major research programmes to develop new radionuclide generators for clinical use in hospitals, using their own nuclear research reactors. This example shows that appropriate technologies of interest only to developing countries, or of marginal interest to a technological one, must be developed by countries needing the technology. Fortunately, in the case of generator technology, there are some advanced developing countries leading the research in this field and sharing their experience and results with centres in less-developed countries.

These reflections on the problems of manufacturing radiopharmaceutical products in developing countries indicate that in the short and medium term, it seems likely that most of these products will have to be imported. One can also safely assume that applications based on RIA will continue to multiply particularly with the encouragement of the IAEA, since there are crucial problems in this area which, perhaps more than in any other area, require international co-operation. It is much more risky to attempt to make a forecast with regard to nuclear imaging since this technique requires considerable capital and is still undergoing rapid development.