Nuclear techniques for sustainable development: Water resources and monitoring environmental pollution

In a range of fields, the IAEA's Laboratories in Seibersdorf and Vienna, Austria are contributing to global environmental efforts

by Pier Roberto Danesi

Pollution of the air, land, and rivers has become a serious global problem threatening public health and the environment. At the same time, about two billion people in 80 countries around the world live in areas suffering from chronic water shortages.

Clean air and sufficient water supplies are critical factors for sustaining the life of plants, animals, and people. Yet under certain circumstances, the generation of wastes due to the large use of chemicals for industrial and residential purposes associated with industrial development can be very harmful for both people's health and the environment. The indiscriminate release into the environment of chemicals can also adversely modify the uptake by living organisms of trace elements, some of which are necessary for life only when present in very small, controlled amounts.

At the IAEA's Laboratories in Seibersdorf and Vienna, Austria, problems of water supply and pollution are some of the important environmental topics that scientists are addressing. Through a broad range of scientific and technical projects and services, the Laboratories develop and transfer technologies with important environmental applications, particularly in developing countries. The broad range of activities include assessments of water resources and their possible contamination, and sensitive analytical studies of toxic metals, pesticides, and other environmental pollutants. The work frequently involves using analytical methods based on radiation and isotopes ranging from neutron activation analysis and X-ray fluorescence to atomic absorption spectrometry and tracer techniques.

This article — the second of a two-part series — presents a selective overview of activities at the IAEA's Seibersdorf Laboratories contributing to efforts for a sustainable development.* In many cases, the Laboratories serve as the institutional centre for research networks involving scientists at analytical laboratories around the world.

Hydrological studies using isotopes

Signs indicate that as human and animal populations grow, the world's water problems are becoming dramatically worse:

In Egypt, estimates are that at the end of this century each man, woman, and child will have only two-thirds as much water as they have today. In Kenya, only half as much. By the year 2000, six of East Africa's seven countries and all five of the nations of the South Mediterranean coast will face water shortages. Poland, Israel, and arid parts of the United States are also approaching a critical situation. In China, 50 cities are already threatened by serious water shortages, the water table beneath Beijing is sinking by up to two meters a year, and a third of the country's wells are thought to be dry. In India over the last 20 years, the water table has plunged 25 metres at Tamil Nandu, while the number of villages short of water in Uttar Pradesh has increased from 17 000 to 70 000.

Dr Danesi is Director of the IAEA's Laboratories at Seibersdorf and Vienna. This is the second of a two-part series of articles in the *IAEA Bulletin* on the work of the Laboratories in fields of sustainable environmental development. Also contributing to portions of this article were Mr Markowicz, Mr Valkovic, and Mr Zeisler of the IAEA's Laboratories. The author further gratefully acknowledges the contributions of Messrs Froelich, Rozanski, and Parr of the IAEA's Department of Research and Isotopes.

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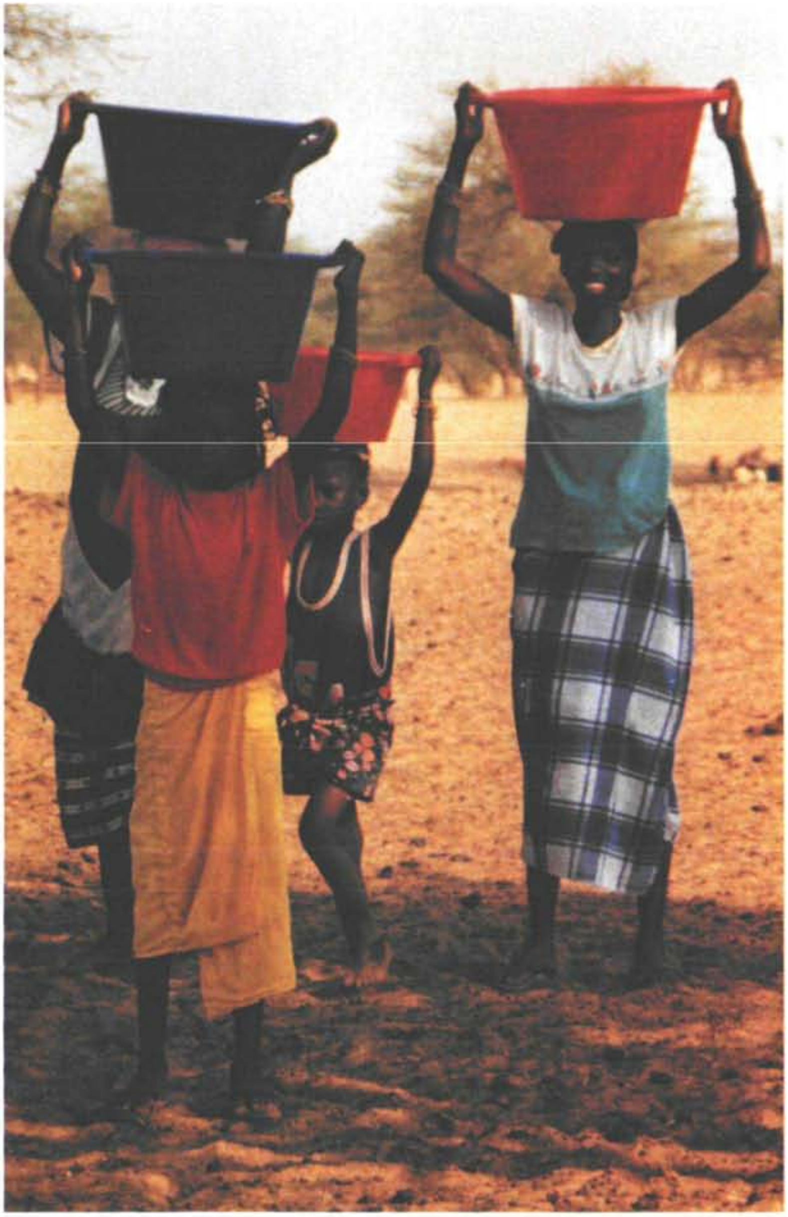
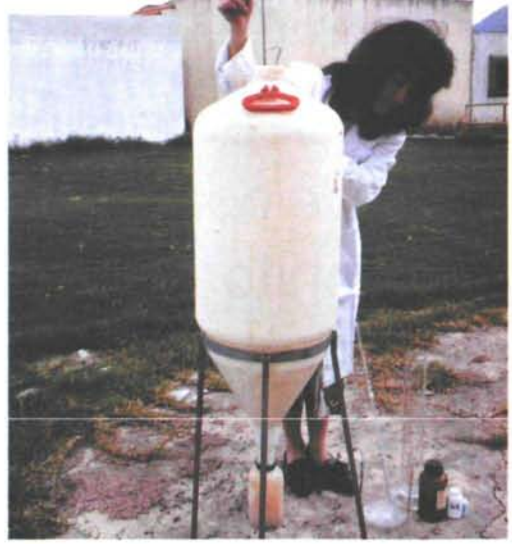
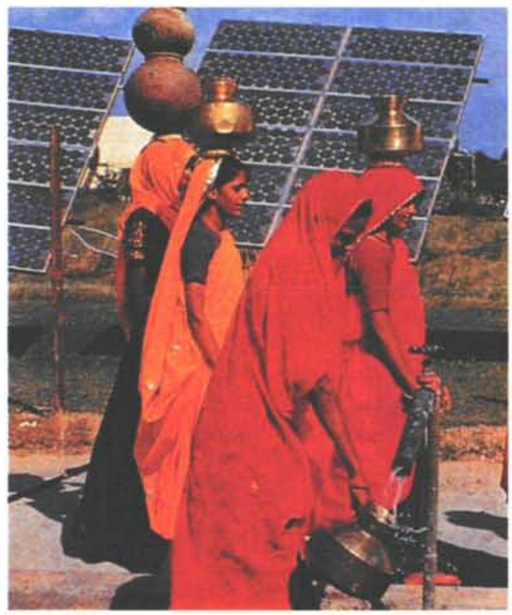
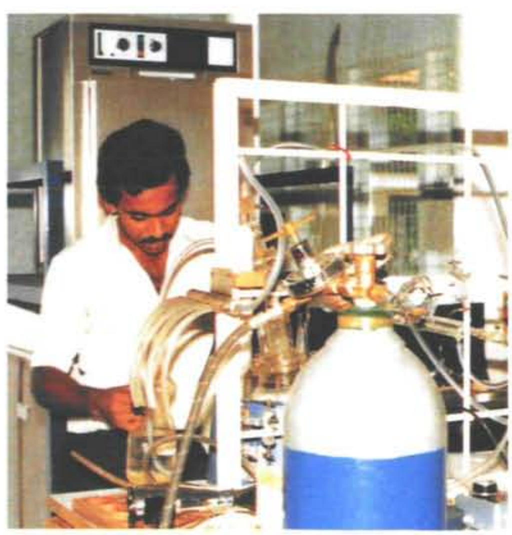








To help countries protect and develop their water resources, the IAEA's Laboratories are involved in research projects around the world. The work typically involves both stable and radioactive isotopes, as well as the use of nuclear and related analytical techniques that are highly sensitive research tools. (Credits: Yurtsever, Aranyossy/IAEA)

Not only are water supplies becoming scarcer but their quality is being degraded. Run-offs from agricultural lands packed with pesticides and fertilizers pollute rivers, streams, and lakes. Storm water flowing from cities and towns carries sewage, heavy metals, oils, hydrocarbons, garbage, chemicals, and organic wastes from animals and dust. Clearly, efforts must intensify to protect existing water resources, develop new sources of sustainable water supplies, and improve water distribution and control.

The assessment of water resources is particularly important in many developing countries where conventional hydrological data are insufficient. But in many other countries, most available water resources are known and exploited, while new, non-explored resources are most probably limited. Therefore, the only way to cope with water demand is to protect the existing resources. This is of crucial importance in both industrialized and developing countries and one of the most challenging tasks for the near future.

The problem is two-fold: protection of water quality, by avoiding or reducing the risk of contamination of water bodies; and protection against depletion of water resources, by means of sustainable exploitation.

Isotope techniques play an important role in the assessment, management, and protection of water resources. Isotopes are a powerful tool to study water bodies, allowing a better appraisal of their capacity and more rational exploitation. They also can be used to evaluate the risk of contamination and to investigate the movement and behaviour of contaminants. Isotopes help to identify flow patterns and to distinguish between water movement and contaminant movement, which is usually slower due to interaction with the rock matrix.

Extensive hydrological data are needed for properly managing water resources, and radioactive or stable isotope tracers of the natural constituents of water — hydrogen and oxygen — are very useful tools for collecting information. Isotope techniques have distinct advantages over conventional ones for tracing water courses. The use of dyes, for example, can suffer from possible losses by adsorption or chemical reaction with dissolved constituents.

The IAEA's Isotope Hydrology Laboratory, which is situated in Vienna, supports Agency programmes in hydrology. Its work includes servicing IAEA research contracts and technical co-operation projects, and measuring isotopes in precipitation for a worldwide network of stations. Laboratory services include analysis of water samples, distribution of reference materials, assistance in the installation of isotope hydrology laboratories in Member States, development of standard measurement procedures, and the organization of analytical intercomparisons.

Facilities are available for analysis of tritium in water, employing electrolytic enrichment followed by liquid scintillation or gas proportional counting; analysis of carbon-14 in water, employing gas proportional counting; determination of deuterium and oxygen-18 stable isotope ratios in water and carbon-13 in carbon dioxide, employing mass spectrometry; chemical analysis of major and trace ions in water; and performance of conductivity and pH measurements.

Environmental isotopes in precipitation

The Laboratory is also collecting, analyzing, and assisting in publishing data on environmental isotopes in precipitation. The IAEA, in co-operation with the World Meteorological Organization (WMO), has been surveying the content of hydrogen and oxygen isotopes in precipitation since 1961. Known as the IAEA/WMO Environmental Isotopes-in-Precipitation Network, the programme has a number of objectives: to systematically collect data for the establishment of temporal and spatial variations of environmental isotopes in precipitation, and, consequently, to provide basic isotope data for the use of environmental isotopes in hydrological investigations within the scope of inventorying, planning, and developing water resources. The network data are especially useful in early stages of hydrological projects, when prompt information is required concerning the distribution of environmental isotopes in precipitation over the investigated area.

Moreover, in recent years two other important uses of the network have become more and more apparent. These are the provision of data for verification and further improvement of atmospheric circulation models, and for climatological investigations.

The precipitation samples—collected by 350 meteorological stations located in 79 countries —are periodically published in a series of publications entitled *Environmental Isotope Data World Survey of Isotope Concentration in Precipitation.* They report tritium, deuterium, and oxygen-18 isotopic compositions, all with their analytical errors as stated by the laboratories performing the analyses. In addition, certain meteorological variables are also recorded (type and amount of precipitation, vapour pressure, air temperature). Approximately 50% of the collected precipitation samples are analyzed by the IAEA Laboratories; the remaining ones in laboratories of co-operating institutions.

Important related aspects are quality assurance and data handling. From the beginning of the network's operation, detailed technical procedures for sampling stations and a standardized data reporting format were introduced. In addition, the IAEA Laboratories organize regular intercomparisons among laboratories of co-operating institutions in Member States to maintain the quality of the analyses.

At the Agency's Hydrology Laboratory, about 500 water samples of the precipitation network are analyzed yearly for deuterium, oxygen-18, and tritium. Oxygen-18 is determined by equilibrating water samples with carbon dioxide, which is then used for the measurement using an isotope ratio mass spectrometer. Deuterium is determined by mass spectrometry on the hydrogen gas evolved from water by reduction with zinc. Carbon-13/carbon-12 ratios, carbon-14, and tritium in natural water samples are determined, after appropriate pretreatment, by highly sensitive measuring instruments (mass spectrometers, gas proportional counters or liquid scintillation counters) with detection limits meeting the low concentrations of those radionuclides in the various samples.

Analyses also are performed for IAEA technical co-operation projects and research contracts. For technical co-operation projects, about 850 samples are analyzed each year for their deuterium/hydrogen and oxygen-18/oxygen-16 ratio; 60 samples for their carbon-13/carbon-12 ratio and carbon-14 content of dissolved carbonates; and 600 samples for tritium. For research contracts 300 water samples per year are analyzed for deuterium and oxygen-18; 100 for tritium; and 30 for carbon-14.

How are data from the IAEA/WMO network used? Apart from widespread use in hydrological studies, the data are used in fields of oceanography and hydrometeorology. Applications of the stable isotopes, oxygen-18 and deuterium, to study various aspects of the water cycle in the atmosphere are numerous and expanding rapidly. Recent studies have confirmed the usefulness of the network database for verifying and improving global-scale general circulation models. The use of the network data for such models, both on a global and regional scale, should improve the actual understanding of mechanisms controlling present climatic conditions. Predictions of future climatic trends caused by both natural and anthropogenic factors thus would become more reliable.

The palaeoclimatological applications of stable isotopes, particularly of oxygen-18, are also well documented. In investigations of climate change, the distribution patterns of stable isotopes in precipitation, as inferred from the network database, provide useful guidelines for interpreting fluctuations in the heavy-isotope content of materials under investigation. They are used in the context of well-established empirical relationships between the isotopic composition of precipitation and key climatic parameters, such as surface air temperature, relative humidity, and amount of precipitation.

Analytical chemistry for pollution studies

Another major topic of interest at the Seibersdorf Laboratories is the analytical chemistry associated with monitoring inorganic and organic pollutants released into the environment by the production of energy and other activities.

Environmental pollution has many different components, of which radioactivity from human enterprises represents just one specific aspect. The major component—in terms of potential adverse health effects—is toxic heavy metals. Recent estimates show that the annual total toxicity of all mobilized toxic heavy metals exceeds the combined total toxicity of all the radioactive and organic wastes generated globally each year.

Even though all stable elements (and some radioactive ones) may be contained in biological and environmental samples, knowledge about the common concentrations and the biochemical, toxicological, and physiological role of elements is still limited to relatively few. These include the major and minor constituents in biological matrices, mineral elements, essential trace elements, and a small number of elements having known adverse effects in biological and environmental systems.

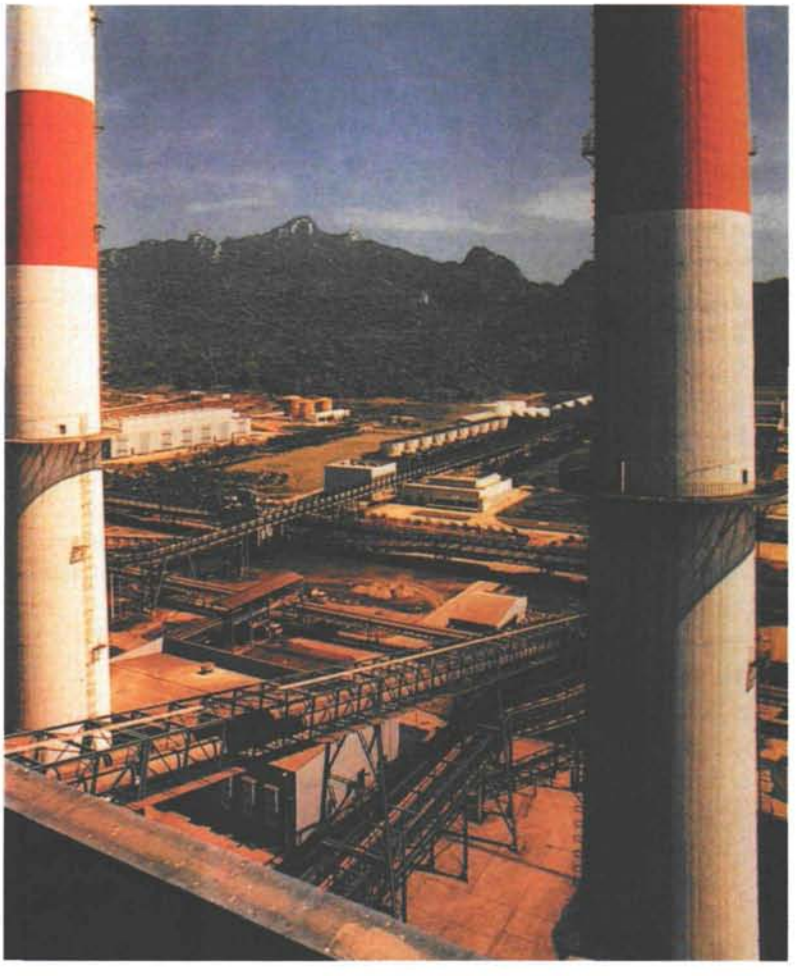
Of the numerous analytical methods available, nuclear and related methods are particularly well-suited for obtaining substantial information on the composition of various environmental and biological samples.

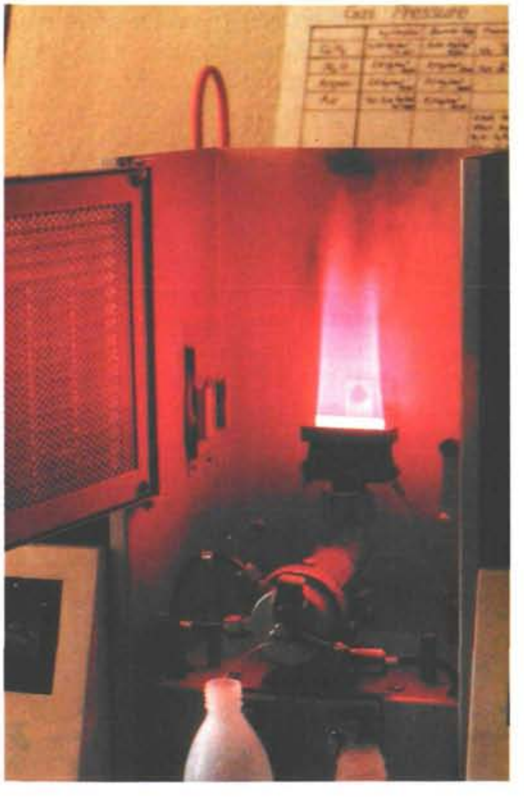
For example, neutron activation analysis (NAA) can be used for the assay of typically 20 to 30 elements in a single small sample of sediments, air particulate matter, or a biological matrix such as mussel tissue. Particle induced X-ray emission (PIXE) or X-ray fluorescence (XRF) methods can be used to determine a similar number of elements. The most benefit can be obtained by combining these techniques or by complementing them with another non-nuclear multi-element technique, such as voltammetry or inductively-coupled plasma emission spectroscopy (ICP-AES).

Nuclear analytical techniques are not sufficient to answer all the questions that one might wish to ask about toxic heavy metals. Nevertheless, they have unique properties which enable them to determine many of the important constituents of non-radioactive solid wastes (e.g. coal fly ash and mine tailings) and to explore how toxic and other trace elements can be removed from them into the surrounding environment.

They are also the techniques of choice for several important kinds of study of air pollution —for example, determining the composition of airborne particulate matter, identifying individual pollution sources, and estimating the long-range transport of air pollutants. Finally, nuclear analytical techniques have important applications in the direct assessment of human exposure to toxic trace elements (e.g. through exposure in the workplace or consumption of contaminated foodstuffs).

Research and monitoring studies of this kind have been supported for many years by the Agency through its Division of Life Sciences and Division of Chemical Sciences, utilizing the experimental support of the Agency's Laboratories at Seibersdorf. These studies have recently been identified as a high-priority problem area under the Agency's medium term programme (for the period up to 1998). The





Various highly sensitive nuclear techniques, often in combination with other methods, are used to analyze pollutants from energy production and other activities. At right, the red glow indicates the presence of strontium in a measurement solution being analyzed by flame atomic absorption spectrometry. The blue flame of the plasma torch provides extremely high temperatures for plasma emission spectroscopy analysis of trace elements in the atmosphere. (Credit: ADB, Seibersdorf Laboratories.)

principal targets for these programmes are nuclear research institutions in developing countries.

Currently an emphasis is being placed on studies of air pollution, solid wastes, and human exposure to mercury. The services provided by the Agency's Laboratories at Seibersdorf utilize state-of-the-art analytical measurements. The analyses performed involve determinations of trace elements in various inorganic materials, in biological substances and foodstuffs, in soils, rocks and minerals, and in rain and other natural waters. They also involve the determination of radioactive contaminants in food products and environmental materials. Approximately 10 000 determinations are carried out per year. Among techniques routinely used are NAA, atomic absorption spectrometry, ICP-AES, ultraviolet spectrophotometry, and conventional and laser-based fluorimetry.

By way of example, during the course of an ongoing IAEA co-ordinated research programme on human daily dietary intakes of nutritionally important trace elements, the Seibersdorf Laboratories characterized more than 400 total diet samples from Australia, Brazil, Canada, China, Iran, Italy, Japan, Norway, Portugal, Spain, Sudan, Sweden, Thailand, Turkey, the former USSR, and the USA.

Most countries provided diet samples from different areas, such as urban, industrialized and rural locations, as well as population groups of different social status. The data included nutritionally important elements (sodium, potassium, aluminum, phosphorus, calcium, manganese, chromium, cobalt, iron, copper, zinc, selenium, magnesium) as well as potentially toxic elements (arsenic, cadmium, mercury, lead).

The work was designed to obtain better information on current daily allowances of nutritional elements, and safe and adequate intakes of other elements. The data from the specific countries and their regions and population groups can be used as a baseline from which deviations can be registered, or to develop specific action plans.

The Seibersdorf Laboratories are also involved in the determination of natural and man-made radionuclides in the environment and food. This work received extensive attention during 1990 through the Laboratories' participation in the International Chernobyl Project organized by the IAEA. It involves the use of techniques such as gamma spectrometry, using sodium iodide and germanium detectors; alpha spectrometry, using silicon surface barrier detectors; beta emission rate measurements, using anti-coincidence equipment; liquid scintillation counting; and chemical separation techniques for different radionuclides.

In the frame of this activity, a set of recommended methods for the determination of key radioactive contaminants (caesium-134 and 137, strontium-89 and 90, americium, plutonium) in air, water, soil, grass, food, and additional reference materials were provided.

The Laboratories additionally have provided analytical support to the Background Air Pollution Monitoring Network of the World Meteorological Organization (WMO). This work involved analyzing precipitation samples and aerosol particles for stations from 30 developing countries. Elements including sodium, magnesium, calcium, potassium, zinc, manganese, nickel, cadmium, lead, copper, and aniónic pollutants such as sulfate and nitrate were analyzed.

Quality control services

Whenever scientific analyses are done, they must be well documented and reliable. The results may be the basis upon which economic, administrative, medical, or legal decisions are taken. Moreover, data for environmental studies must be comparable and compatible over national, regional, and even global study areas. Many laboratories may be involved in carrying out required measurements.

Through its Analytical Quality Control Service (AQCS) programme, the IAEA's Laboratories help national laboratories check the quality of their work. These national laboratories typically use atomic and nuclear analytical techniques for analysing nuclear, environmental, and biological materials for major, minor and trace elements, and for radioactive and stable isotopes.

This programme includes training in the field of quality assurance, intercomparison of methodology, issuance of standard samples, and reference analysis of samples submitted by outside laboratories. The programme's most visible part are the standard samples, issued as "intercomparison materials" and "certified reference materials" (CRMs).

These standard samples and CRMs play a leading role in the economical transfer of measurement quality. The certification laboratory can characterize an entire lot of the material and then share this characterization with the entire measurement community by simply distributing individual samples from this lot to the participating laboratories. This economy of labour — coupled with the ability to achieve compatibility with international standards in one's own laboratory — has made the CRMs a popular and economical means of obtaining and measuring a laboratory's measurement compatibility and accuracy of results.

The AQCS programme currently stocks about 35 different materials that relate to analytical work carried out to determine environmental quality and anthropogenic impact. These materials include matrices relating to the lithosphere (soils, plants, and anthropogenic materials such as fly ashes and sewage sludges) to agriculture and food (soils including phosphates, plants, milk products, grains, animal, fish and bivalve tissues).

A number of intercomparison materials and CRMs from environmental impact studies relating to air quality, fertilization, and industrial and municipal waste have been obtained as well.

Instrumentation for environmental studies

In the field of instrumentation and nuclear electronics, the Seibersdorf Laboratories also are involved in projects of environmental interest.

A system for monitoring stack emissions, for example, has been designed and constructed in Seibersdorf. This computer-based, card-mounted system is used to monitor gaseous samples containing radioactive particulate, iodine, and noble gases released from a reactor stack or from other nuclear facilities. The monitor consists of a particulate detector and an iodine detector placed in a compact shielded sample chamber, a noble gas detector mounted inside the chimney, a vacuum pump, an air flow meter, control valves, a programmable logic controller, amplifiers, single channel timing analyzer, and high voltage suppliers. A computer is used for counting, data acquisition and processing, presentation, recording, and the reporting of results.

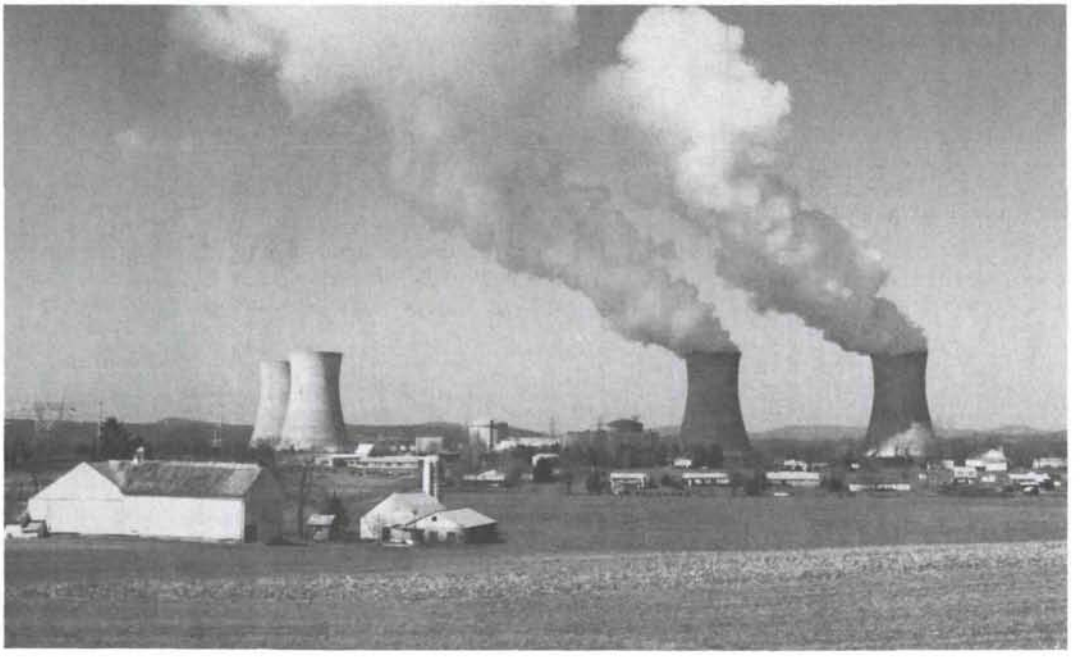
Two of these stack monitoring systems already have been used in Greece and Portugal.

Other work is directed at the development of methodologies and applications of X-ray fluorescence (XRF) analysis. This technique is based on the measurements of the energies and intensities of the characteristic X-rays excited in the sample of interest by electromagnetic radiation. It has long been recognized as a simple and powerful method for the analysis of airborne particulate material and suspended solid material in natural water and sludge samples.

In response to requests from some IAEA Member States, the Laboratories also are supporting work related to an "early-warning" system for environmental radiation monitoring in Europe and the Middle East. The system is intended to ensure that authorities are quickly alerted to radiation releases from a nuclear accident.

One of the system's major components is a remote station capable of collecting data from a radiation monitor in the field and then automatically transferring them by public telephone or telex lines to the central station. A computer at the central station collects the data from many remote stations connected to the network, processes them, reports on radiation distribution to relevant authorities, and triggers an alarm when the radiation levels exceed preset limits.

Currently, specialists at Seibersdorf are working to develop universal software for the central station which can be used in a network that includes various remote monitoring stations. ❒



The Seibersdorf Laboratories have developed a system for monitoring emissions from nuclear power plants and other facilities.