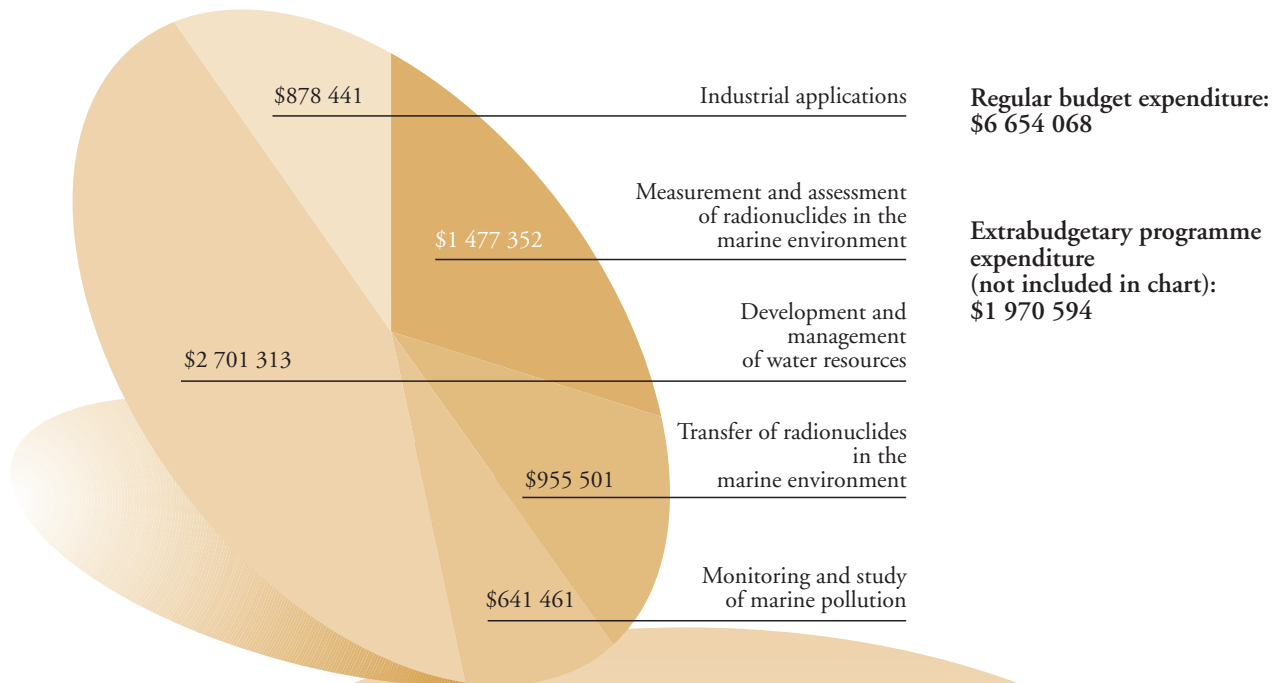


# MARINE ENVIRONMENT, WATER RESOURCES AND INDUSTRY



To protect the marine environment through improved capabilities to monitor and assess radioactivity and the use of nuclear and isotopic techniques to enhance understanding of the oceans and marine pollutant transfers and behaviour. To assess the need and, where appropriate, promote the development and transfer of isotope and radiation technology and applications for environmentally sustainable industrial development and the solution of practical problems in hydrology and the management of fresh-water resources.

## Programme objective

Activities in the marine environmental field marked the United Nations International Year of the Ocean. They included an international symposium on marine pollution and the opening of the new premises of the Marine Environment Laboratory in Monaco. In addition, a major field programme in three oceans was carried out to better understand the distribution of radionuclides in the oceans of the world. Collaboration with the

European Union in Mediterranean studies provided valuable new information on the processes of material transport. In the field of hydrology, a CRP on the application of isotope techniques to investigate groundwater pollution was completed. The data collected will help in the control of pollutants and mitigation of their effects. Efforts were made to integrate the Agency's work in water resources management with the work of other

United Nations agencies. For example, the Agency and WMO signed a Memorandum of Understanding to strengthen the Global Network for Isotopes in Precipitation, which will permit wider use of isotope data in hydrology and climatology. Progress was made in work related to industrial applications. In this connection, a new CRP on the radiation processing of indigenous natural polymers to convert natural products into useful materials was initiated.

## Measurement and assessment of radionuclides in the marine environment

One of the major events of the United Nations International Year of the Ocean was the convening of a symposium on marine pollution in Monaco in October. The symposium was hosted by the Principality of Monaco and was co-sponsored by the IOC of UNESCO, the IMO, UNEP and the Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée (CIESM). New developments included: the identification of the sources of pollution; the behaviour and fate of contaminants in sea water, biota and sediments; the use of radioactive and non-radioactive tracers for studies of transport and circulation processes in the world's oceans and seas; studies of radioactive waste dumping sites and nuclear weapon test sites; local, regional and global computer modelling of the transport of contaminants; and high sensitivity analytical measurements of contaminants with emphasis on nuclear and isotopic methods. Information on global and regional marine pollution study programmes was presented and future trends in marine pollution studies were identified. In addition, the new premises of the Marine Environment Laboratory in Monaco, the only such laboratory in the United Nations system, were officially inaugurated during the symposium.

A ministerial meeting of Black Sea countries, organized within the framework of an Agency technical co-operation project on marine environmental assessment of this region, was also held during the symposium. Environmental ministers signed the 'Black Sea Declaration', which stresses the important role played by the Agency in upgrading the capabilities of Member States in the region to assess the marine environment. In this connection, a cruise was also

organized to sample sea water, sediment and biota in the Black Sea with the participation of Member State laboratories in the region.

As part of a project on Marine Radioactivity Studies in the World Oceans (MARS), supported by the Government of Japan, three cruises took place to the Antarctic, the northeast Atlantic Ocean and the Arabian Sea in co-operation with institutes from Germany, India and Italy. The objectives were to sample sea water, biota and sediment to better understand the distribution of radionuclides in the world's oceans and the sources which have introduced anthropogenic radionuclides, such as global fallout, former nuclear weapon tests and former radioactive waste dumping sites. Samples were collected and are being analysed in several Member State laboratories. The data will be included in the Global Marine Radioactivity Database (GLOMARD).

A computer model was developed for the assessment of the radiological situation in connection with the dumping of radioactive wastes in the Far Eastern Seas. The collective effective dose equivalent of the annual intake of marine products in Japan was estimated to be only 0.8 man-Sv. About 90% of the dose derives from caesium-137, most of which is due to the consumption of fish. The total dose from radioactive wastes is about 5% of that from global fallout, which is attributed to the testing of nuclear weapons in the atmosphere. The dominant dose is from natural polonium-210 in shellfish, which contributes 99.9% of the total dose.

In the Agency's Analytical Quality Control Services (AQCS) programme, a sample of lagoon sediments from Fangataufa Atoll was prepared for a worldwide intercomparison exercise on marine radioactivity measurements. After preparation and preliminary testing, the samples were sent for radionuclide analysis to 110 laboratories in Member States. The analytical results obtained confirmed good performance for caesium-137 analysis. However, the analysis of plutonium isotopes in marine samples needs further improvement in many laboratories.

## Transfer of radionuclides in the marine environment

Chemical and radiochemical analyses were completed on a wide variety of samples from the hydrothermal

vent zone off Milos Island as part of the European Union sponsored 'Aegean Sea Hydrothermal Fluxes' project. Particle dynamics studies using time series sediment traps have shown that vertical fluxes of aggregates were on average one order of magnitude higher near the vent zone than outside the vents. In periods of maximum sedimentation, the downward flux of organic material was 30–100 times higher at the vent site. Settling particles differed between sites not only in quantity but also in their composition. Higher particle fluxes and downward carbon transport near the vent fields appeared to be a consequence of enhanced biological activity, which was closely linked to the geothermal emissions. This relationship was supported by the discovery of hyperthermophilic bacteria in the sinking particles collected near the vents, as well as the relatively low carbon-13 isotopic levels in these particles, an isotopic signal which is typical of that measured in bacterial mats and surface sediments associated with hydrothermal vents.

Vent emissions are often enhanced in trace element and natural radionuclide content. Analyses were carried out to examine this aspect at sites, both inside and outside of the vent zone. For the most part, concentrations of a suite of trace metals and the natural radionuclides polonium-210 and lead-210 in sinking particles were similar at both sites. The higher downward fluxes of some metals, as well as polonium-210 and lead-210 measured at the vent site were thus attributed to the higher particle fluxes related to venting activities. Similarly, small snails found grazing on the carbon-rich bacterial mats in the vent zone did not show elevated polonium-210 or lead-210 concentrations when compared with concentrations of these radionuclides in similar organisms from outside the vent area. More specifically, their radionuclide concentrations were much lower than levels measured in vent associated worms living in the deep sea. These observations suggest that bacteria associated with the Milos mats are not an important vector for polonium-210 and lead-210 enrichment in higher feeding levels of this particular benthic food chain.

In the Mediterranean Targeted Project II (MATER), which is being carried out in collaboration with the European Union, the Agency is using radionuclides such as lead-210 and plutonium-239 and 240 to measure particle scavenging and sedimentation rates in the western Mediterranean Sea. The relationship between the inventories of these radionuclides in deep sea sediments is being used to better understand the nature of the sedimentation regimes in this relatively

productive region of the Mediterranean. A sediment core from the productive Malaga upwelling area contained a much higher content of plutonium-239 and 240 relative to lead-210 than is normally observed in the basin. The enhanced plutonium deposition at this site was attributed to the nature of the sedimenting particles, which were mainly biogenic and are known to be excellent 'scavengers' of dissolved plutonium in the water column. Because of the different affinity of plutonium-239 and 240 and lead-210 for certain types of biological particles, the ratios of these radionuclides in underlying sediments may prove to be useful tools in determining the type of sedimentary regime in a given area of the Mediterranean.

Experimental nuclear application studies were focused on the use of radiotracers to assess the bioavailability, retention and transfer factors of radiologically important radionuclides and toxic heavy metals in marine molluscs which are routinely used in monitoring programmes. In one study, low energy gamma emissions of lead-210 were used to quantify the bioaccumulation of lead in mussels which are the species of choice in various 'mussel watch' type heavy metal monitoring programmes. The resultant bioaccumulation factors for whole mussels of approximately 200 were some two orders of magnitude lower than those reported for other trace metals in these bivalve molluscs, indicating that the uptake of lead by mussels in the marine environment is a very inefficient process. Both the slow uptake rate and long retention time of lead limit the ability of mussels to record short term variations of lead concentrations in surrounding waters, a fact which must be considered when defining the appropriate sampling frequency for mussels used in the biological monitoring of lead contamination.

In a separate laboratory study, a clam species typical of Arctic waters was exposed to sediments from the Kara Sea that had been labelled with a mixture of radiotracers of cobalt, zinc, silver, cadmium, caesium and americium. The transfer of the radionuclides from sediments to clams was followed for six months and it was found that direct bioaccumulation from the sedimentary phase was minor compared with the amount taken up from the interstitial water between the sediment grains. Therefore, exposure to sediments which characteristically have low radionuclide distribution coefficients ( $K_{d,s}$ ) between sediment and water, such as those from Abrosimov Bay, leads to a relatively higher bioaccumulation factor in the clams compared with those living in sediments with higher  $K_{d,s}$ . Knowledge of site specific bioavailability variations is crucial for

adequately modelling radionuclide and heavy metal transfer in Arctic as well as other benthic ecosystems.

An assessment of the technological enhancement of radioactivity from agrochemical and non-nuclear industrial activities was carried out by examining levels of the natural radionuclide polonium-210 in specific coastal areas of China, the Syrian Arab Republic and Turkey. Along both the northern coast of China and Turkey's Black Sea coast, macroalgae, fish and shellfish were sampled near river outflows containing elevated organic phosphorus levels derived from agrochemical applications as well as in 'control' areas away from riverine inputs. High polonium-210 concentrations are known to be closely associated with many phosphorus compounds. However, for both areas there was no clear indication of elevated polonium-210 levels in biota living near rivers discharging into the sea. Hence, any perturbation of the natural radiation regime in these areas from agrochemical inputs via rivers is expected to be very small. On the other hand, in one of the main ports in the Syrian Arab Republic, where large quantities of phosphate ore have been exported for more than 20 years, polonium-210 levels in sediment and sea water were higher than those in corresponding samples collected along the coast. Such enhanced polonium levels could lead to a higher radiation dose being received by the local population consuming seafood from the port area.

## Monitoring and study of marine pollution

The use of carbon isotope techniques, coupled with gas chromatographic separation, to identify the sources of organic materials present in the marine environment was further developed and its potential applications to palaeoclimatology were evaluated. A significant correlation has been found between the  $\delta^{13}\text{C}$  cholesterol of suspended particulate and seawater carbon dioxide concentrations in the southern Indian Ocean.

Two new reference materials were produced, a sea plant homogenate (IAEA-140) and a marine sediment (IAEA-383), which are now available to the international scientific community. These materials are certified for pollutants such as organochlorine pesticides, petroleum hydrocarbons, PCBs, trace elements and methylmercury.

In collaboration with UNDP, assistance was provided to the Black Sea Member States to establish a regional

pollution monitoring network and to obtain high quality analytical data for trace contaminants. In several laboratories instruments were installed and staff were trained for the optimum use of these instruments. A 'mussel watch' type pilot biomonitoring exercise was implemented for organic contaminants in collaboration with several national laboratories in the region. Samples were collected by the various participants and first information on the regional distribution of trace organic contaminants in mussels and sediments has been obtained.

## Development and management of water resources

A CRP on the application of isotope techniques to investigate groundwater pollution was completed. Work focused on the application of isotope techniques for the assessment or mitigation of urban groundwater pollution due to domestic wastes and sewage disposal as well as landfill sites, seawater intrusion and pollution from agricultural practices. The results of this CRP, published as a technical document, have verified that the isotopes of nitrogen, boron, sulphur and oxygen in dissolved sulphate, and iodine-131 can be applied to distinguish pollutant sources and identify their transport pathways in groundwater systems. These data have practical applications in dealing with hydrological problems encountered in technical co-operation projects, such as the UNDP/RCA/IAEA project on 'Access to Clean Drinking Water'.

Another CRP was completed that focused on the use of isotopes for analyses of flow and transport dynamics in groundwater systems. Different approaches for improved quantitative evaluation of isotopes with the goal of more reliable estimates of the dynamic parameters of flow and pollutant transport in groundwater were applied to actual field cases by the participating institutes to verify the mathematical modelling procedures required for this purpose. Several computer programs for practical applications of different formulations were also developed and tested. The results of this CRP have provided a scientific basis for different conceptual model formulations and extensive data on their field applications under various hydrogeological settings.

A completed CRP studied the use of isotope techniques in water resources investigations in arid and semi-arid

regions. In addition to dealing with specific isotope methodologies in arid zone hydrology, and particularly with studies related to the evaluation of the replenishment of groundwater resources under present climatic conditions and the effects of over-exploitation, this CRP contributed to more effective utilization of isotope methods in the implementation of technical co-operation projects related to groundwater resources assessment and management in arid zones. In addition, the CRP resulted in better isotopic characterization of the present recharge to groundwater in northern Africa (Algeria), identification of non-renewable groundwater resources (palaeo-recharge) in selected African and Asian regions, and determination of the contribution of surface water and irrigation return flow to the present groundwater recharge of specific arid/semi-arid regions in Egypt and in various parts of Asia.

Through a recently completed CRP on isotope aided studies of atmospheric carbon dioxide and other greenhouse gases, the analytical precision of the participating laboratories was significantly improved to the high level necessary to determine relatively minuscule natural isotopic variations. The CRP also achieved a remarkable improvement in the comparability of analytical results by strengthening quality assurance methods and establishing measurement protocols, this being a necessary pre-requisite for merging the existing data sets from different atmospheric observation networks. Combined measurement of the stable isotope ratios of greenhouse gases and their concentrations provides the only direct method for the assessment of regional releases of these gases. The advances made in this CRP will facilitate the use of isotope techniques in the verification of the Kyoto Protocol and other international agreements on the reduction of greenhouse gases in the atmosphere.

An Advisory Group meeting was held in November in Kozhikode, India, to integrate isotope methods more effectively into water projects in the Asia and Pacific region. After reviewing the possible areas of use and the applicability of isotope techniques to the major water resources issues in the region, the meeting considered possible ways and means for their wider scale utilization. Several constraints were identified and recommendations made which will be fully taken into account in the design of future programmes. The recommendations included: improved lines of communication between practising hydrogeologists and isotope scientists; training of hydrogeologists to facilitate the integration of isotope techniques in hydrological practices; development of a guide for the use of

isotope techniques in hydrology; and assistance to universities to include a course in isotope hydrology in their curricula.

The services of consultants were used to delineate the needs, requirements and strategy to be used for more effective programming of Agency technical co-operation activities in the specific field of isotope hydrology in groundwater applications. It was emphasized that there was a need to further harmonize the Agency's technical co-operation projects with national priorities in water resources development and management in Member States. The following high priority areas were identified: groundwater recharge in arid zones; management of aquifers affected by salinity; groundwater pollution; and urban hydrology.

At the fourth co-ordination meeting for a regional Model Project on isotopes in groundwater resources development, held in June in Dakar, all four countries involved in phase I of the project (Egypt, Ethiopia, Morocco and Senegal) reported technical achievements with a direct impact on water resources management practices in their countries. In Egypt, the project results have been used to prepare a comprehensive hydrogeological map that will be used in the future for managing water resources in the area. In Senegal, the main objective of the project was to re-evaluate the potential of groundwater resources in the Cape Verde Peninsula region (i.e. Dakar and vicinity, which suffer a severe water shortage) for the supply of drinking water. The isotope studies provided critical data for the sustainable management of the most important groundwater aquifers in the vicinity of Dakar. Isotopic studies in two regions of Morocco led to a better understanding of the aquifer systems. In one of the regions (Tafilalt), the studies indicated that the Infracenomanian aquifer is not being replenished and it was therefore decided to close off five artesian wells to avoid exhaustion of the resource. In the other area (Guelmin), it was found that artificial recharge of the Seyyad aquifer by surface water (to be collected in new dams) is feasible. The potential area for this artificial recharge was also identified on the basis of the isotope study. In Ethiopia, the replenishment of water resources was assessed for the Moyale region, where three million people suffer from recurrent droughts. The results show a widespread recharge of the groundwater through rainfall. However, the rate of modern recharge was shown to be only 10% of previous estimates. The study highlighted the sustainable potential of two sedimentary and fractured rock aquifers in the region which can be used for rural water supply.

Technology transfer to Costa Rica and Venezuela from the Agency within the framework of an ARCAL XVIII programme on nuclear and related techniques in dam and reservoir leakage studies was completed in 1998. The techniques transferred have been incorporated as an additional tool in activities related to dam safety monitoring. Following the success of this project, a similar regional project has been initiated in Africa, with 22 AFRA countries requesting participation because of leakage problems in dams and reservoirs. Owing to the visible impact and simplicity of the nuclear techniques, and in view of the extensive occurrence of dam and reservoir leakage problems in Member States, the use of nuclear techniques in this field is being included as one of the subjects for the new 'thematic planning' approach in the Agency's technical co-operation programme.

Under a technical co-operation model project in Costa Rica, a chemical laboratory was set up for water and gas analysis at the Instituto Costarricense de Electricidad to support monitoring which will sustain the production of steam at the Miravalles geothermal field and development of other exploration areas. In addition, the effects of injecting cooler saline wastewater produced in the power plant back to the subsurface ('re injection') to maintain steam pressure at the production wells of the geothermal field have been monitored to avoid possible negative impacts and to protect the environment from pollution.

In support of development and technology transfer to Member States, an instructional manual entitled *Isotopic and Chemical Techniques in Geothermal Exploration, Development and Use: Sampling Methods, Data Handling and Interpretation* was prepared to guide exploration and monitoring activities that use geochemical and isotopic tools in geothermal investigations. This manual is intended for scientists working in geothermal projects, either in the exploration, exploitation or development phases for both low and high enthalpy systems, and for the investigation of freshwater resources.

The Isotope Hydrology Laboratory of the Agency's Laboratories issued five new reference materials in 1998, increasing the total number of these materials to 38. More than 800 samples of these reference materials were distributed to laboratories around the world.

In response to a 1997 General Conference resolution, a number of laboratories in developing Member States were visited and proficiency tests carried out to identify

those that were able to provide analytical services to technical co-operation projects in isotope hydrology. Of the laboratories visited, six (three in Latin America, two in Africa and one in the Asia and Pacific region) were selected for further consideration as regional resource centres to provide analytical support in the region.

In September, an Internet Web site (<http://www.iaea.org/programmes/ripc/ih/index.html>) dealing with the development and management of water resources was inaugurated. The site includes the *Water and Environment News* newsletter and links to other relevant activities such as the Global Network for Isotopes in Precipitation (GNIP) database and the Isotope Hydrology Information System (ISOHIS).

A preparatory meeting for the establishment of a joint IAEA-WMO GNIP Scientific Steering Committee was held in Vienna. At this meeting a Memorandum of Understanding (MoU) was finalized. The MoU was signed by the Director General and the Secretary General of WMO in December. It paves the way for greater collaboration between the Agency and WMO and permits wider use of isotope data by the hydrology and climatology communities represented by the International Association for Hydrological Sciences, World Climate Research Programme, and the International Geosphere-Biosphere Programme.

Efforts to seek synergies with other United Nations system organizations resulted in discussions at the Subcommittee on Water Resources of the United Nations Administrative Committee on Co-ordination that identified projects where immediate collaboration is possible. The Agency was invited to participate in a new system-wide initiative to develop mitigation strategies for polluted drinking water. The initial focus of this work is on arsenic contamination in drinking water in Bangladesh. This initiative is being co-ordinated by UNICEF, with the Agency and UNESCO responsible for hydrogeology activities.

An ad hoc meeting, organized by the Agency jointly with the WMO-World Climate Research Programme (WCRP) and hosted by UNESCO, was held in Paris in December to discuss the scope and objectives of a new initiative entitled the 'International Programme for Isotopes in the Hydrological Cycle'. Conceived as an interagency co-operative programme, the main goal of this initiative is to integrate isotope hydrology in water sciences as a teaching discipline at universities around the world and establish (through the UNESCO

International Hydrological Programme) national committees to conduct activities related to the further development of isotope hydrology and its application in the water and climate sector of countries. It was recommended that the Agency, in co-operation with UNESCO and WMO–WCRP, take the lead in preparations for the launch of this programme. To this end, a task force was established to co-ordinate further activities.

## Industrial applications

Sterilization of single use medical products continues to be the major industrial application of radiation technology around the world. New applications based on the radiobiological effects of ionizing radiation are emerging, such as blood irradiation and tissue sterilization. A new CRP was initiated to facilitate the introduction of radiation sterilization into the pharmaceutical industry to sterilize or decontaminate pharmaceuticals and pharmaceutical raw materials. The objectives include: identification and quantification of radiolytic products; establishment of maximum tolerated dose for the radiation response pattern in a particular product; and testing of safety and screening for toxicity and mutagenicity.

Two Advisory Group meetings, in Budapest in March and in Vienna in October, held to identify emerging new applications in the radiation processing of materials, particularly polymers, demonstrated the increasing attention being devoted to this subject by industry. The new radiation application programmes studied in these meetings included: electron beam curing of advanced composites used in the aircraft industry; new fibre materials for applications under extreme conditions; stimuli-responsive materials obtained through the radiation grafting of track membranes; pre-crosslinking of thermoplastics; radiation vulcanization of natural rubber latex; cross-linking of thicker and bulky polymeric products; and cross-linking of Teflon at high temperature. In addition to reviewing the current and emerging applications for electron beam processing, the meeting assessed the use of ion beams for processing materials, in particular polymers. The dramatic changes brought about in the surface properties of polymers irradiated with ion beams include: greatly enhanced resistance to chemical attack; induced electrical conductivity; significantly lowered permeability to gaseous molecules; and dramatically increased hardness and abrasion resistance.

In a CRP on the validation of protocols for the evaluation of corrosion and deposits in pipes by radiography, including the quality assurance aspects of non-destructive testing (NDT) measurements, metallic pieces with known and simulated corrosion defects were prepared and experimental results achieved in many of the participating laboratories. These specimens were then exchanged within the network for inter-laboratory quality control testing.

The services of consultants were used to study the area of digital radiography in industrial applications. It was recommended that research on the following NDT methods be supported in view of their cost advantages and greater industrial safety: radiography with digital image processing; film digitization with archiving and digital image processing; and imaging plate radiography. In related work, a report entitled *Non-destructive Testing: A Guidebook for Industrial Management and Quality Control Personnel* was completed for publication.

A CRP on radiotracer technology for unit operation studies and unit process optimization was initiated. Its main purpose is to upgrade the capability of radiotracer groups in developing countries, refine, consolidate and systematize existing know-how, and promote new applications. The main areas of research will be: expert systems for experiment design; customization of mathematical software; signal decomposition for better flow visualization; residence time distribution coupling with computer fluid dynamics modelling; optimization of multidetection units; automatic fast and safe tracer injectors; and quality control of data and accreditation to ISO standards. Case studies from catalytic cracking units in the petroleum industry, grinding and flotation in mineral ore processing, model identification and kinetic determination of the crystallization process, and testing the efficiency of sedimentation and aeration tanks of waste water treatment plants are the major targets of the CRP.

An Advisory Group meeting was convened in Vienna in May to study emerging applications of nucleonic control systems in industry. At the meeting the current status of the technology was evaluated and recommendations were made on the best ways to further develop the new applications and transfer them to developing countries. It was recommended that prototypes of portable low cost and low activity double beam gauges be designed and manufactured for niche applications in the natural resource mining and processing industries.