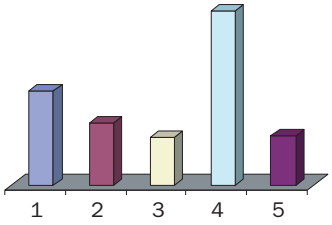
MARINE ENVIRONMENT, WATER RESOURCES AND INDUSTRY

PROGRAMME OBJECTIVE

To improve Member State capabilities to: (i) monitor and assess radioactivity in the marine environment for its protection, and use nuclear techniques and environmental isotopes to better understand and assess marine processes and pollution; (ii) integrate appropriate isotope and nuclear techniques in the planning and resource management of the whole water cycle and better understanding of human induced hydroclimatic impact on the water cycle and its interaction with other environmental systems; and (iii) adapt and utilize radiation and radiotracer technologies to improve industrial productivity and minimize environmental hazards.

Regular budget expenditure: $5 759 160

Extrabudgetary programme expenditure (not included in chart): $691 379



1. Measurement and Assessment of Radionuclides in the Marine Environment: $1 269 095
2. Transfer of Radionuclides in the Marine Environment: $832 708
3. Monitoring and Study of Marine Pollution: $638 576
4. Development and Management of Water Resources: $2 360 689
5. Industrial Applications: $658 092

OVERVIEW

Agency activities dealing with the marine environment focused on the quantification of marine levels and distributions of radioisotopes, the processes that control them and their ultimate fate and the way in which they can be used in association with other nuclear and isotopic techniques to understand broad problems of marine pollution. In addition, the work programme emphasized capacity building, quality assurance activities and education and training in marine environmental protection. New information was collected on radioactivity in several major oceanic regions using traditional and new automated techniques, and has been added to the Global Marine Radioactivity Database (GLOMARD). Laboratory and field training and research studies on the transfer of nuclear and non-nuclear contaminants in contrasting marine ecosystems were prominent. The ocean carbon dioxide cycle, a critical component of climate change, was the focus of a study of the production of particulate carbon and its removal from the oceans.

In its water resources management activities, the Agency focused on identifying and working with other partners in developing isotope methodologies and in assisting Member States through its technical co-operation programme. Specifically, an inter-agency initiative with UNESCO was launched to increase collaboration with the aim of integrating isotopes in hydrology research and education. New projects were formulated in co-operation with other agencies to develop isotope methodologies for improving global water resources assessment and understanding hydroclimatic processes. These included the estimation of submarine groundwater discharge and global monitoring of rivers. Technical co-operation projects in isotope hydrology, with a number of international agencies and the US Geological Survey as partners, were carried out in Ethiopia and Bangladesh. And research began on a new analytical technique for the isotope analysis of water that requires minimal infrastructure and operational skills.

In the area of industrial applications, the Agency assisted oil producing countries in Asia and Latin America in using radiotracers to enhance the recovery of oil from wells. At a symposium on radiation technology in emerging industrial applications, held in Beijing, the use of radiation for facilitating conventional wastewater treatment and upgrading of natural polymers to produce value added products were identified as promising applications in industry. In the field of non-destructive testing, the Agency developed protocols to determine corrosion and deposits in small diameter pipes.

MEASUREMENT AND ASSESSMENT OF RADIONUCLIDES IN THE MARINE ENVIRONMENT

A CRP on Worldwide Marine Radioactivity Studies (WOMARS) that reviewed the present sources of anthropogenic radionuclides in the marine environment and studied the open ocean distribution of radionuclides in the water column and sediment ended in 2000. The results showed that the present caesium-137 inventory in the marine environment from global fallout is approximately 158 PBq for the Pacific and Indian Oceans, and 83 PBq for the Atlantic and Arctic Oceans. The present caesium-137 inventory from local tropospheric fallout from nuclear weapon tests carried out in the Pacific Ocean is estimated to be about 72 PBq. In comparison, the current caesium-137 inventory in the Atlantic and Arctic Oceans and their marginal seas from Sellafield and Cap de la Hague nuclear fuel reprocessing plant releases is estimated to be about 24 PBq. The Chernobyl accident contributes about 11 PBq to the present inventories of caesium-137 in the European seas, mainly in the Baltic and Black Seas. Whereas the present average concentrations of caesium-137 in surface waters of these seas are estimated to be about 60 and 40 Bq/m^3, respectively, the worldwide average due to global fallout is about 2 Bq/m^3.

In related work, the world's oceans were divided into latitudinal bands to investigate changes in the average concentrations of strontium-90, caesium-137 and plutonium-239+240 over time in order to estimate the mean residence time of these radionuclides in the water column and to predict present concentrations. Such information is important for the estimation of radiation doses to humans through the consumption of seafood. The results indicate that the mean residence time for strontium-90 and caesium-137 in surface waters has been the same, about 25 years, while for plutonium-239+240 the residence time is about 13 years. The CRP was supported by extrabudgetary funding from Japan.

Through the Marine Radioactivity Studies in the World Oceans project, supported by extrabudgetary funds from Japan, IAEA-MEL analysed samples collected in the northeast Atlantic Ocean, the south Indian Ocean and the northwest Pacific Ocean. Several radionuclides (tritium, carbon-14, strontium-90, caesium-137, plutonium and americium isotopes) were analysed in water samples collected at different water depths at northeast Atlantic Ocean radioactive waste dumping sites around 46°N and 17°W. No clear evidence of radionuclide leakage from dumped containers with radioactive wastes was found. However, remarkable peaks in radionuclide concentrations were observed at medium depths between 2000 and 3000 m, which have not previously been observed. The conclusion is that high latitude injection processes must be responsible for the observed evolution of concentrations below 1000 m, downwelling high surface radionuclide concentrations to medium depths.

"No clear evidence of radionuclide leakage from dumped containers with radioactive wastes was found."

Surface and water column samples collected during an expedition to the south Indian Ocean (north of the Kerguelen Islands) were

analysed for their radionuclide constituents, as well as for salinity, density and temperature gradients. Radiotracers such as carbon-14, caesium-137, plutonium-238, plutonium-239+240 and americium-241 were used to study the evolution of anthropogenic radionuclide input at southern latitudes. Low radionuclide concentrations found in the south Indian Ocean reflect slow worldwide redistribution and mixing of global fallout radionuclides, resulting in a considerable dilution of the global fallout signal in the southern hemisphere. In addition, zooplankton (biological particulates) was collected to measure the concentration of natural polonium-210 and anthropogenic plutonium and americium isotopes. It was found that zooplankton, bearing different elemental and radionuclide compositions, can be used as a biomarker of open ocean water column processes.

"Member State radioanalytical laboratories have found Agency reference materials to be important tools for maintaining high quality assurance standards."

IAEA-MEL completed radiocarbon measurements in seawater samples taken at ten stations in the southwestern North Pacific during the Agency's 1997 Pacific Ocean expedition, in collaboration with the Japan Atomic Energy Research Institute and the University of Arizona. Five stations were located close to GEOSECS stations, and five were in the vicinity of Bikini and Enewetak Atolls, which may be influenced by former nuclear weapons testing. Compared with the GEOSECS data (from samples collected in 1973), the Agency's results show an increase of radiocarbon in intermediate waters. Furthermore, it is estimated that bomb produced carbon-14 inventories in the water column have increased by more than 20% during the last 24 years. Vertical profiles of carbon-14 at the stations near Bikini and Enewetak Atolls show a similar general trend to that found at other stations; therefore, no effect of close-in fallout from nuclear weapons tests has been found. This contradicts Agency data on plutonium-239+240 obtained from the same set of samples which showed that the Northwest Pacific Ocean has been affected both by global and close-in fallout. This latter input is in a different, more reactive, physico-chemical form, which leads to more rapid removal in the ocean.

Member State radioanalytical laboratories have found Agency reference materials to be important tools for maintaining high quality assurance standards. In the framework of the Agency's Analytical Quality Control Services (AQCS) programme for radionuclides in the marine environment, a fish sample from the Irish and North Seas (IAEA-414) was prepared, tested for any inhomogeneities and sent to almost one hundred laboratories participating in this new global intercomparison exercise, after which it will be issued as a new Certified Reference Material.

Underwater gamma ray spectrometry is a new technique that was developed by the Agency to complement or replace the traditional sampling–sample analysis approach for applications with space–time constraints, e.g. large areas of investigation, emergency response or long term monitoring. Both high efficiency sodium iodide and high resolution germanium spectrometers have been used to investigate contamination by anthropogenic radionuclides in a variety of marine environments. For example, a gamma ray survey of seabed sediment offshore from the Sellafield nuclear reprocessing plant was carried out with the aim of obtaining estimates of the distributions of caesium-137 in the area. The survey, carried out in co-operation with the Centre for Environment, Fisheries and Aquaculture Science of the United Kingdom, showed caesium-137 concentrations in surface sediment between about 100 Bq/kg to about 900 Bq/kg dry weight, with the latter value restricted to a small area some 2 km northwest of the outfall. As the recent releases from Sellafield were negligible compared with releases in the past, remobilization of caesium-137 from sediment plays a dominant role in the observed changes in caesium-137 levels.

The radionuclide levels observed at present in the marine environment are very low, thereby necessitating the use of highly sensitive analytical systems. A Monte Carlo simulation code was developed to optimize the background characteristics of low level, high purity germanium gamma spectrometers. A 15 cm thick lead shielding was found to be the optimum shielding for most gamma spectrometry applications.

Another important group of radionuclides in the marine environment is represented by long lived alpha emitters of both natural origin (such as uranium and thorium isotopes) and anthropogenic origin (such as plutonium and americium isotopes). These radionuclides have traditionally been analysed by semiconductor alpha spectrometry (SAS). However, SAS is limited in its sensitivity, resolution and mass of samples used for analysis. A new analytical method developed at IAEA-MEL using inductively coupled mass spectrometry (ICP-MS) allows much lower detection limits for plutonium and uranium isotopes and a much smaller sample size for analysis, in the case of seawater by two orders of magnitude.

"Certain nuclear techniques are unique tools for enhancing our understanding of how radionuclides and conventional pollutants move through the marine environment."

As part of a regional technical co-operation project on marine environmental assessment of the Black Sea region, the Agency organized an international scientific cruise involving six Black Sea Member States: Bulgaria, Georgia, Romania, the Russian Federation, Turkey and Ukraine. Contaminants in the marine environment were assessed, with a focus on anthropogenic radionuclides, to study oceanographic processes which control the fate of pollutants using radionuclides as tracers. The results will be used to assess the distributions and inventories of radionuclides in relation to input sources and oceanographic processes and to improve predictive models for the dispersion of contaminants and comparative assessments of natural and anthropogenic radionuclides.

TRANSFER OF RADIONUCLIDES IN THE MARINE ENVIRONMENT

Certain nuclear techniques are unique tools for enhancing our understanding of how radionuclides and conventional pollutants move through the marine environment. The Agency's new state of the art experimental aquaria facilities in Monaco continue to serve as a focal point for training and research studies on the transfer of nuclear and non-nuclear contaminants in contrasting marine ecosystems. However, a freak storm in April 2000 resulted in the complete destruction of the subsurface water pumps and intake pipes, causing major delays in the work of IAEA-MEL. Despite this setback, several experimental studies were completed during the year.

It has been shown that organisms at the base of the marine food chain are all important in governing the cycling and redistribution of elements and materials in the sea. Furthermore, we know that marine zooplankton feeding on microscopic plant life (phytoplankton) produce faecal pellets that play a major role in the biogeochemical behaviour of many radionuclides and their transfer through the water column. These zooplankton have enhanced capacities to accumulate natural polonium-210, the main deliverer of radiological dose through the marine pathway, and this high bioaccumulative capacity is particularly evident in oceanic regions of low biological productivity such as those typically found in the tropics. A collaborative project between the Australian Nuclear Science and Technology Organisation and the Agency measured the transfers of polonium-210, and its grandparent lead-210, from water to phytoplankton and from phytoplankton to zooplankton and their faecal pellets. The experimental results support the interpretation of field based results that the lead-210: polonium-210 ratios in water are greater than unity in oceanic

surface waters because of their differential removal, and that the removal is biologically mediated, primarily by zooplankton faecal pellets.

Radiotracers can be used to experimentally test the ability of certain organisms to serve as bioindicators of coastal marine contaminants, i.e. human made radionuclides and toxic heavy metals. With shrimp of growing importance in the world fisheries economy, the Agency carried out a study where edible shrimp were exposed for several months to bottom sediments contaminated simultaneously with a mixture of radiotracers of cadmium, silver, zinc and cobalt. Periodic gamma spectrometric measurements of the live shrimp clearly showed a similar direct transfer from sediments to shrimp of cadmium, silver and zinc which was, however, three times greater than that of cobalt. Comparing these transfer factors with known distribution coefficients for the same metals in sediments indicates that transfer rates from sediments to shrimp cannot be predicted solely from the relative differences in sediment–water distribution coefficients for sediments. Other factors such as sediment type, grain size and organic matter content also play a role in the transfer of the contaminant metal from sediment to the organism living on them.

"Radiotracers can be used to ... test the ability of certain organisms to serve as bioindicators of coastal marine contaminants, ..."

Bivalve molluscs are distributed throughout the world and are also an important food source. Because they filter directly from water organic particles for food, they have been proposed as potentially ideal bioindicators of water borne contaminants. Using new culture techniques developed specifically for the temperature controlled IAEA-MEL aquaria system, the bioaccumulation of americium-241, cadmium-109, caesium-134, cobalt-57, silver-110m and zinc-65 was examined from water and food in tropical mussels and oysters. The two long lived radionuclides (caesium and americium) are only weakly bioaccumulated in these warm water bivalves. When the contamination source is removed, caesium is rapidly lost from both species. In contrast, all the radiolabelled heavy metals were rapidly bioaccumulated, with generally higher concentration factors observed in the oysters than mussels. Both bivalve species accumulated more zinc and silver than the other contaminants tested, and in the case of oysters almost all the zinc accumulated was retained for several weeks after the organisms were transferred to non-contaminated sea water. This suggests that, in particular, oysters would be an ideal bioindicator of zinc contamination in tropical coastal areas.

An in-depth temporal analysis of transuranium nuclide concentrations in deep water sediment trap samples (1000–2000 m depth) from the northwest Mediterranean Sea, coupled with known changes in transuranium inventories in the overlying water column during the last two decades, indicates that sinking particles reaching the sea floor out of deep waters can account for 26–72% of the total annual plutonium loss and virtually all of the americium removal from the water column. A further observation that americium: plutonium activity ratios in unfiltered Mediterranean sea water are on average six times lower than those typically found in North Pacific waters suggests the existence of a specific mechanism for enhanced particle scavenging and removal of americium from the biologically poor waters of the open Mediterranean. Based on these oceanographic measurements and the proximity of the Mediterranean Sea to one of the world's largest desert regions, it is now believed that the unique and frequent inputs of Saharan dust particles, which are known to be active sites for americium sorption, are likely responsible for the observed rapid removal of americium to Mediterranean sediments.

The production of particulate carbon and its removal from the surface water of the oceans has a strong bearing on understanding the

carbon dioxide cycle and resolving other questions related to global climate change. The Agency's unique time-series measurements of particle flux in the northwest Mediterranean, taken over a 13 year period from 1987 to 2000, show a clear seasonal variation of high carbon flux during winter–spring months and a much diminished flux in the summer–autumn period.

Such field experiments on organic carbon sequestration have also highlighted the influence of Saharan dust events in mediating these climate related processes. Saharan dust, which carries a high load of wind borne nutrients, is now believed to actually fertilize and enhance biological particle production in the normally nutrient starved Mediterranean waters. This process, which is highly variable over time, could account for the three to four-fold inter-annual fluctuations in carbon flux which were observed during the 1990s. Such data sets, derived from collaborative studies with other scientists, underscore the true magnitude of the seasonal changes in carbon export from surface waters to depth.

MONITORING AND STUDY OF MARINE POLLUTION

Key results from inductively coupled plasma-mass spectrometry (ICP-MS) and accelerator mass spectrometry (AMS) measurements demonstrate that these techniques effectively complement radiochemical analyses of transuranic elements. Even more importantly, the isotopic information provided by ICP-MS and AMS can be used to identify the source of an observed contaminant. Strategies to exploit the higher resolution modes afforded by the Agency's Finnigan Element double-focusing ICP mass spectrometer provided interference-free plutonium isotopic data which can be used to discriminate contamination from different weapons detonations. ICP-MS and AMS are now being used to detect the presence of uranium-236 as an indicator of nuclear activities and processes. Such data cannot be obtained by traditional radiometric methods. In addition, the greater sensitivity provided by ICP-MS and AMS for many key nuclides has resulted in the collection and processing of smaller samples to obtain the required information. Isotopic analysis is also being used for trace metal assays through isotopic dilution analysis in the characterization of Agency reference materials.

Carbon isotope studies provide information on the source of organic material in marine sediments. A newly developed procedure using high performance liquid chromatography (HPLC) effectively separates petroleum hydrocarbons and biomarker lipids for compound-specific isotopic analyses. Three isotopic carbon projects examined the origin of organic material in marine sediments in diverse locations. The first project, off the western coast of South Africa, evaluated long term changes in the carbon cycle at the ocean–atmosphere interface of the Benguela Current upwelling system. The study showed a gradual decrease in the carbon isotope ratio over the past 4.5 million years (Pliocene–Pleistocene epochs). These measurements are a key component in the ultimate objective of determining the historical carbon dioxide exchanges between the oceans and the atmosphere. Another investigation, on the eastern continental slope margin of the Faroes–Shetland Channel, found high concentrations of mid-chain ketones in sediments at one drill site. The carbon isotopic composition in these substances was markedly different from that typical of marine algae. As these types of compounds could be formed by clay-catalysed reactions of triglycerides at high temperatures, the carbon isotope measurements are indicative of contamination from drilling activities. In the third investigation, different depositional environments on the Lorca Basin (Spain) were defined on the basis of the biological inputs to each marine sediment type.

"ICP-MS and AMS are now being used to detect the presence of uranium-236 as an indicator of nuclear activities and processes."

Speciation analyses help elucidate the environmental behaviour and bioavailability of metal pollutants in the environment. Mercury contamination in the surface waters of French Guyana was investigated as part of an evaluation of the impact of gold mining. The study assessed the distribution and transport of mercury in two typical water basins affected by mercury derived from gold mining operations: the Inini River basin, and the Sinnamary River and estuary. The results indicated that methyl mercury accumulates to very high levels in deep anoxic waters of the Petit-Saut reservoir, located on the Sinnamary River, and is released downstream of the dam into the river. As a result of this contamination, carnivorous fish collected in the Sinnamary catchment basin contain excessive amounts of methyl mercury.

"... novel and sensitive methods for the analysis of organotin compounds and their degradation products in marine sediments and biota were developed at IAEA-MEL."

The use of organotin compounds containing tributyltin (TBT) and triphenyltin (TPhT) in marine paints causes pollution in the marine environment. Because these anti-fouling compounds are highly persistent in marine sediments, continuous monitoring and surveys in areas with no historical data provide information on the extent and effect of pollution. To this end, novel and sensitive methods for the analysis of organotin compounds and their degradation products in marine sediments and biota were developed at IAEA-MEL. These techniques were used to analyse samples from both Qatar and the United Arab Emirates (UAE). Oysters from the UAE contain these anti-fouling agents at concentrations that might represent an ecotoxicological risk. High ratios of TBT and TPhT over its metabolites indicate recent inputs of these active biocides in the UAE. In comparison, organotin compounds were not significantly present in the sandy sediments and fish samples from both countries.

Quality assurance programmes assist Member State national laboratories and regional laboratory networks in producing reliable environmental data. These programmes implement global intercomparison and intercalibration exercises which characterize homogenized marine samples for their ultimate use as reference standards. Two new Reference Materials (sediment sample IAEA-408 and fish sample IAEA-406) were prepared and characterized for chlorinated pesticides and petroleum hydrocarbons. Regional reference materials for chlorinated pesticides and petroleum hydrocarbons, comprising one sample of sediment and one sample of biota were prepared for the Regional Organisation for the Protection of the Marine Environment (ROPME). A reference material was also produced specifically for laboratories in the Black Sea area. This sediment sample was analysed for chlorinated pesticides, petroleum hydrocarbons (BS1/OC) and various heavy metals (BS1/TM).

Contaminant screening provides key information on environmental quality to aid in coastal zone management. Responding to a request from Monaco, IAEA-MEL analysed harbour sediment samples for chlorinated pesticides, PCBs, petroleum hydrocarbons, organotin compounds and a range of heavy metals. Contaminant levels reflected normal port activities and no notable pollution hot spots were identified. The data aided management decisions for the disposal of waste material from the extension of the harbour. In this connection, water samples from the aquarium at the Oceanographic Museum of Monaco were analysed for petroleum hydrocarbons, PCBs and chlorinated pesticides. The results refuted the hypothesis that such substances, possibly remobilized by construction activities at the adjacent port, caused the photo bleaching of coral in the aquarium.

In related work, a contaminant-screening project was undertaken in the UAE and Qatar in collaboration with ROPME. Traces of petroleum aliphatics, indicative of diesel fuel, were found in marine waters at only one site,

namely on the east coast of the UAE. These contaminants also appeared in sediments and biota from this location. Generally, sediments and biota from Qatar and the UAE exhibited insignificant concentrations of organic contaminants. The relative composition of hydrocarbons in sediments from one location (Ras Al-Nouf, Qatar) signified recent, but minor, inputs of such contaminants. High mercury levels in fish and elevated cadmium concentrations in shellfish were measured in biota from the UAE. Biological samples from Qatar had lower contents of such heavy metals.

A number of important outcomes resulted from a just concluded CRP, sponsored by the Swedish International Development Agency, on the use of radiotracers in studying the distribution, fate and effects of pesticide residues on biota in the tropical marine environment. For example, capacity building in laboratories and training in the analysis of pesticides has helped several Member States evaluate pesticide pollution and its effects in tropical marine environments. Quality control and quality assurance procedures, including regular participation in intercomparison exercises and the use of certified reference materials to ensure the quality of data, were adopted by many of these laboratories. Research using carbon-14 labelled compounds was introduced in many Member State laboratories, as was gas chromatographic techniques. In most cases, these techniques were not in use before the start of the CRP. The research contracts awarded helped augment the human resources available to evaluate pesticide problems in developing countries.

DEVELOPMENT AND MANAGEMENT OF WATER RESOURCES

The Agency's *Medium Term Strategy* calls for greater use of partnerships with other international bodies to maximize the benefits of programme activities to the Member States of both organizations (see Box 1). The pursuit of such synergies was the driving force behind the Joint International Isotopes in Hydrology Programme (JIIHP), a new IAEA–UNESCO initiative that was launched to integrate isotope hydrology techniques in the water sector of Member States. Through JIIHP, there will be greater participation by and information dissemination to a wider group of practising and research hydrologists in Member States through UNESCO's International Hydrological Programme (IHP) network. The JIIHP was endorsed by UNESCO's General Conference and a Memorandum of Understanding for its implementation is being discussed by the two organizations.

An Advisory Group meeting to evaluate the potential benefits of isotope monitoring of global rivers concluded that isotope ratios in river water are an excellent proxy for precipitation and integrate the spatial and temporal variability in the hydrological cycle. A global network of isotopes in river water, therefore, can be a powerful new tool for monitoring climate change and/or land use patterns, as well as facilitating integrated water resources management. A river network will also supplement the long running IAEA–WMO Global

BOX 1. INCREASING THE VISIBILITY OF THE AGENCY'S WORK IN SUSTAINABLE DEVELOPMENT

The Agency highlighted its activities in isotope hydrology and their contribution to global water resources management at the Third World Water Forum at The Hague and the World Bank's Water and Sanitation Forum in Washington, D.C. In the Hague, the Agency projected its role in the various water related programmes of the United Nations system as part of an exhibition that included FAO, HABITAT, the UN Department of Economic and Social Affairs, UNEP, UNESCO, UNICEF, WHO and the World Bank. At the World Bank Forum, the Agency highlighted its contribution to projects that are investigating the arsenic contamination of drinking water in Bangladesh. This presentation, in particular, provided an opportunity to communicate directly with the professional and management staff of various agencies involved in the water sector. ■

Network for Isotopes in Precipitation (GNIP) and increase the utility of isotope data for water balance and climate change studies. The Agency is formulating the next step in this area, namely a CRP in collaboration with UNESCO and WMO that will design a river monitoring network.

The role of isotopes in the assessment of submarine groundwater discharge (SGD) was reviewed at another Advisory Group meeting

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that also had UNESCO's IHP and the Intergovernmental Oceanographic Commission as partners. Comprising as much as 50% of total terrestrial freshwater runoff, SGD constitutes a substantial freshwater resource in coastal areas, but can also be a source of pollution for the marine environment. The meeting concluded that a unique methodology based on a combination of radioactive isotopes of radium and radon, and stable isotopes of oxygen, hydrogen, and strontium, can be developed to assess and quantify SGD, something that is difficult to achieve with non-isotopic methods.

The presence of elevated arsenic concentrations in drinking water continues to be a major public health issue in Bangladesh. At the request of, and in co-operation with the Government of Bangladesh, WHO, the World Bank, UNDP and UNICEF, the Agency organized a proficiency test to evaluate the quality of arsenic measurements made by about 20 laboratories in Bangladesh. The test will not only improve the quality of the measurements, but will also provide a greater degree of confidence in the analytical surveys performed by different laboratories. This is critical, since the results of the arsenic analysis of groundwater are being used to make policy decisions regarding the continued use of individual or community water supply wells. Clearly, decisions based on inaccurate or inconsistent data would have unintended and adverse social and economic impacts on the population.

Greater integration of isotope hydrology into water resources management practices in Ethiopia was an important accomplishment in 2000. Specifically, a national plan for groundwater resources assessment was drawn up at an Agency workshop organized in co-operation with the US Geological Survey and involving the Ethiopian Science and Technology Commission, the Ministry of Water Resources, the Ethiopian Geological Survey, Addis Ababa University and consulting hydrogeologists. The plan has been submitted for government approval and, upon implementation, will guide national and international efforts for groundwater resources assessment and management over the next 10–15 years.

A CRP on the use of isotopes for the analysis of flow and transport dynamics in groundwater systems assessed the applicability of different conceptual hydrological model formulations under different geological settings and at different spatial scales. One of the main accomplishments was the development of software by selected institutes on 'lumped parameter modelling' and 'compartmental modelling–mixing cell' approaches. Both software packages, together with a user's manual for these applications, will be available on CD-ROM.

A new application of the stable isotopes of dissolved molecular oxygen was tested to estimate oxygen consumption and replenishment rates in polluted rivers in a CRP that ended in 2000. These estimates are difficult to obtain by non-isotopic means. In addition, a new technique was tested for labelling fine suspended sediments with technetium-99m. This technique allows the simultaneous measurement of water and sediment phases in water pollution studies.

Sulphur isotopes, along with other isotopes, are useful in studying the origin of geothermal acidity, the estimation of reservoir temperatures and the investigation of scale formation in geothermal installations. This was the main conclusion of a CRP on the applications

of isotope techniques to problems associated with geothermal exploitation that ended in 2000. The results of this CRP will have a strong impact on this aspect of the implementation of Agency technical co-operation projects. For example, investigation results for some geothermal fields will be used directly for improved geothermal reservoir management strategies. Other geothermal systems with similar acidic problems will benefit from the established sulphur isotope systematics and isotope-chemical models in the CRP.

In related work, an Advisory Group meeting reassessed the available Agency reference materials in the field of stable isotope measurements. Careful measurements resulted in the consistent calibration of these materials for sulphur stable isotopes. This will improve the quality assurance of sulphur isotope measurements, which are extensively used in many hydrological and geochemical studies.

In many parts of the world, increasing development and migration have led to greater demand and impact on aquifer systems in urban areas. Improved methods for the management of groundwater resources are thus issues of high priority in many cities. A recently completed CRP evaluated the usefulness of geochemical and isotopic techniques for applications in major urban aquifers. Although many of the isotope techniques were demonstrated to be useful in non-urban situations, it was not clear how they could be applied in urban situations. The CRP demonstrated that isotope techniques might be most useful for understanding changes in groundwater recharge and for distinguishing multiple sources of recharge resulting from the effects of urbanization.

Soil erosion and sedimentation represent serious global threats to sustainable agricultural production, environmental conservation and dam sustainability. An Advisory Group meeting concluded that the 'basic' nuclear techniques developed earlier in related CRPs on soil erosion were valid for sediment 'fingerprinting' studies. However, the participants agreed that further development was required to construct a framework and methodology under which the nuclear techniques would be implemented for monitoring sedimentation control strategies.

The Agency published a manual for using isotopic and chemical techniques in geothermal reservoir development and management. Providing information on essential nuclear and complementary methodologies for a multidisciplinary approach to geothermal exploration, development and monitoring, the manual provides comprehensive procedures for carrying out isotope and geochemical investigations of geothermal systems, i.e. sampling, analysis and data interpretation. It is expected to facilitate personnel development in Member States and the implementation of future Agency technical co-operation projects in this field.

"The CRP demonstrated that isotope techniques might be most useful for understanding changes in groundwater recharge ..."

Improving quality assurance procedures for chemical analyses of geothermal waters in Member State analytical laboratories was the Agency's goal in holding a third round of intercomparison exercises. Thirty-five laboratories in Asia, Africa and Latin America participated in these exercises, with five of them serving as reference laboratories. These exercises serve as a diagnostic tool for the participating laboratories to identify their performance in water chemistry analyses.

In related activities, the Agency designed and tested a vacuum distillation procedure for the preparation of environmental water samples for tritium analysis at low activity levels. The new procedure ensures a high quality of tritium analyses in spite of the steadily decreasing tritium levels in hydrological samples and the associated increasing sensitivity to laboratory contamination by local sources. A sample pyrolysis line was installed for organic and inorganic substances coupled to mass spectrometric oxygen isotope ratio analysis. This will allow long term monitoring

of the oxygen isotopic composition of the available Agency stable isotope reference materials and ensure high quality standards of materials sold around the world as part of the Agency's AQCS. And the Agency tested a simplified sample preparation method for sulphur isotope measurements in a collaborating laboratory in Poland. The method will improve conventional sample preparation techniques, thereby further enhancing the quality of sulphur isotope measurements.

"In Niger, the isotope results are being used to constrain the flow and transport model of the aquifer system and determine those most vulnerable to pollution."

A two phase technical co-operation Model Project on isotopes in groundwater development was implemented by the Agency for north and west Africa. Egypt, Ethiopia, Morocco and Senegal participated in the first phase (from 1995 to 1998) and Algeria, Mali, Niger, Nigeria, Sudan and Uganda took part in the second phase (from 1997 to 2000). In Algeria, the isotope results indicate that the aquifers in the Djanet and Tin Seririne basins and in the Tidikelt region are not being replenished by modern precipitation. These findings strongly indicate that the water supply of the city of Tamanrasset will rely more on the mobilization of local renewable resources through appropriate subsurface dams. In Niger, the isotope results are being used to constrain the flow and transport model of the aquifer system and determine those most vulnerable to pollution. In northwestern Nigeria, critical data for the various sources of recharge and replenishment of the Rima Group aquifer were obtained. This information can be used in the management of groundwater resources in the Wurno irrigation scheme area and identification of areas suitable for artificial recharge. In Uganda, isotope results provided data on the replenishment of water resources in towns north of the capital Kampala. The information can be used to better manage the available groundwater.

Nuclear techniques can be very effective in measuring environmental pollution. The Agency conducted a sediment contamination study in Montevideo Bay; the surrounding areas of the Rio de la Platathat showed that heavy metal contamination was confined only inside the bay, but did not extend to the Rio de la Plata. This is crucial information to the authorities for planning remedial actions, which are now feasible because of the limited extent of the contamination.

In an Agency technical co-operation project in Costa Rica on the sustainable management of groundwater in the Central Valley, results demonstrated that nitrate in the groundwater originates from nitrogen fertilizer in areas of coffee plantations and from human wastes in areas without adequate sewerage systems. Labelled (nitrogen-15) fertilizer was used to demonstrate that the current nitrogen fertilizer management practices in high density coffee plantations are economically and environmentally inefficient. Only 6–40% of the total amount of fertilizer applied was being absorbed by coffee plants. The data collected from this project were later disseminated through a regional Agency–National University symposium.

Technology transfer is a critical component of the Agency's technical co-operation programme. One project focused on the use of artificial tracers (krypton-85 and hydrogen-3) to determine the re-aeration rate of polluted rivers in Ecuador. Tracer determined re-aeration rates in the Quito metropolitan region were much higher than those estimated from empirical techniques and allow better design of a planned water treatment facility for the city. The Agency also trained staff from the local implementing organization in the tracer technique. The simplicity of the technique and the availability of equipment and trained personnel in the country led other municipalities to request the local organization to help them in similar experiments.

INDUSTRIAL APPLICATIONS

A CRP on radiotracer technology for engineering unit operation studies and unit process

optimization ended in 2000. Among the achievements were the development and validation of software for tracer data modelling and interpretation for problem solving in major industrial processes, including fluidized beds, sugar crystallizers, trickle bed reactors, cement rotary kilns, flotation cells, grinding mills, incinerators, wastewater treatment units and interwell communications in oil fields.

Radiotracers are very competitive tools for enhancing oil recovery in oil fields, both onshore and offshore. Secondary and tertiary recoveries are used to collect oil that remains in the pores and fissures of the rocks. An Agency CRP developed and validated new radiotracers for investigation of secondary and tertiary recoveries. And a multitracer technique was tested and put into service in Argentina, Brazil, China and Viet Nam.

Radiotracer and nucleonic gauge technologies continue to be an active component of technical co-operation national and regional projects. The Agency carried out a number of activities in these areas for use in the petroleum and petrochemical industries. For example, radiotracer and sealed source technology for troubleshooting inspection in petroleum refineries was introduced for the first time in African countries. In Ghana and Nigeria this technology is being used for problem solving through column scanning and leak detection in heat exchangers.

The papers presented and discussed at an international symposium in Beijing on radiation technology in emerging industrial applications showed the environmental friendliness of this technology. The advantages of radiation processing in upgrading naturally available macromolecules into useful products for health care and agricultural applications have reached pilot scale demonstrations. In addition, the participants noted the use of radiation technology in mitigating environmental problems, particularly in the purification of flue gases and the decontamination of industrial and municipal waste water.

The results from a CRP in the Asia–Pacific region funded by extrabudgetary contributions from Japan highlighted the unique role of radiation processing in upgrading natural polymers into useful products. Such natural polymers as chitin, chitosan, alginates and carrageenans that are abundant in the region exhibit properties that can be used in the health care industry, agriculture and wastewater treatment. For example, radiation degraded polysaccharides — chitin/chitosan, alginates and carrageenans — can induce growth and suppress environmental stress on

"Radiotracers are very competitive tools for enhancing oil recovery in oil fields, both onshore and offshore."

plants, and also enhance antimicrobial activities. Irradiated chitosan, when applied as a coating agent on fruits, can delay ripening and spoilage, thereby increasing the shelf life of the fruit. In the health care industry, radiation processed chitin/chitosan is a biocompatible, biodegradable material that is also bactericidal. Hydrogels prepared from chitosan possess antibacterial properties that prevent infection and stimulate re-epithalization. Controlled drug delivery systems have also been prepared using radiation grafted chitosan. Environmental applications include the irradiation of chitin, which can significantly improve the efficiency of recovery of chitosan from biowaste. Due to its unique chemical structure, chitosan can be used as an adsorbent to treat various aqueous effluents containing heavy metals and toxic organics and dyes.

The detection and measurement of internal corrosion in industries using piping systems can help to improve the safety and reliability of industrial plants. Data from a CRP that ended in 2000 on the validation of protocols for corrosion and deposit determination in small diameter pipes by radiography will be used to draft an international standard. A major observation was that standard radiographic procedures have been validated, and protocols for identification and measurement of corrosion attack and deposits have been prepared.