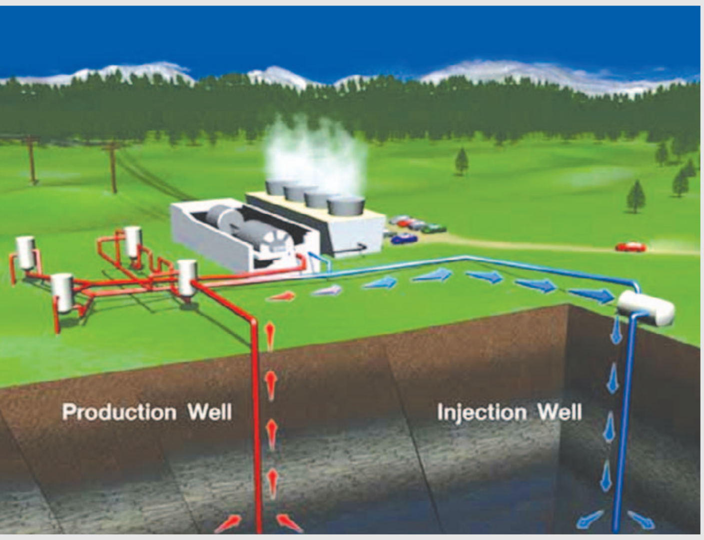
Harnessing energy from the heart of the earth

A project of the Regional Cooperative Agreement for Research, Development and Training in Nuclear Science and Technology in Asia and the Pacific (RCA)

In the search for increased sustainable energy and energy security, countries in Asia and the Pacific are turning their attention to a source of power beneath the Earth's surface: geothermal reservoirs. These are reservoirs of extremely hot water found underground in the pores and fractures of rock. Due to the presence of magma chambers or to friction between tectonic plates in the Earth's crust, the rock itself reaches a very high temperature, and it is this that heats the water. Drilling into these reservoirs releases the water and steam which can be used to drive turbines and generate electricity. Already geothermal power in the region generates about 3,500 megawatts of electricity, but studies indicate the potential for this natural resource to supply much more-and it is a clean, cost-effective, indigenous and renewable form of energy with far fewer harmful emissions than fossil fuels. The RCA has established a project to arm Member States with the latest nuclear techniques for subsurface hydrological exploration to assist in the selection of suitable sites for the development of geothermal power stations and the management of geothermal reservoirs.



A schematic showing running of turbine for power generation by geothermal steam from a production well and pumping down the condensed water in an injection well to sustain production.

To determine if a reservoir is suitable for exploitation and, if so, how it can be exploited sustainably and with minimal environmental impact, it is critical to have accurate information about its subterranean workings and its hydrological and geological surroundings: the nature of the heat source; the temperature of the reservoir; the sources of the reservoir's water supply and how quickly it gets replenished; the properties of geothermal fluids (water and gas), the processes shaping them, and the paths they travel. This information is critical for economic as well as environmental reasons. Capital investment costs for drilling are high, so it is important to site wells where there are strong chances of success. It is also important to be able to predict how the reservoir's behaviour will be affected-such as through changes in pressure, temperature and fluid flow-when it's connected to a fully-operational power plant.

Tapping energy from geothermal reservoirs requires great care and precision. Extracting water and steammay drain the reservoir faster than nature can replenish it. It may also reduce the pressure inside the reservoir; therefore generally the used geothermal water / steam condensate is pumped down an injection well to sustain production. Environmental isotopes and artificial radiotracers help manage the reservoir by providing information on the movement of injected fluid and on reservoir characteristics. Re-injection of the thermal fluids into the geothermal reservoir also solves the problem of disposing of potentially hazardous substances such as boron which may be present in the geothermal water and steam.

Injection of tritium tracer (370 GBq activity) at Kamojang, Indonesia for investigation of residence time and recovery of injected water

The best way to obtain all this information is through a combination of chemical and nuclear technologies. The RCA project has helped Member States acquire and develop the expertise to use these technologies. With financial and technical support from the International Atomic Energy Agency, the RCA has organised expert missions, workshops and training courses to build local capabilities to conduct sophisticated site investigations, analyse water samples for determination of environmental isotopes and chemical quality, apply isotope techniques (with the aid of both natural isotopes and artificial radiotracers), develop computer-simulated hydrological models of reservoir systems, conduct inter-laboratory comparison exercises, and devise reservoir management strategies.

Hot springs in Mae Hong Son area, Thailand, Hot springs in Mae Hong Son area, Thailand

Over the course of the RCA project, participating countries have carried out isotope investigations on 33 new geothermal prospects (about 130 springs). As a result, the Philippines National Oil Company has now commissioned an additional 49 MWe geothermal power, and has completed the exploration work for the development of 160-300 MWe. Indonesia has committed to increasing its current geothermal capacity of 807 MWe to 2500 MWe by the year 2015. India has developed a pilot geothermal power plant at the Tattapani geothermal field in Saurguja District, Madhya; and Pakistan is proceeding with a thorough exploration of the Murtazabad area, which has shown great promise as a source of geothermal power.

The RCA's work has made an important technical contribution to the expansion of geothermal energy resources in Asia and the Pacific. Its activities have also brought the application of advanced isotope techniques to the attention of the region's energy sector. The techniques are now becoming recognised as essential tools in geothermal exploration, development and reservoir management, and the number of organisations adopting this nuclear know-how continues to grow.

Production wells at Kamojang Geothermal Field , Indonesia

Radioisotope techniques in combination with geochemical and geophysical techniques are very effective at the exploration stage in evaluating a reservoir's properties, fluid characteristics and energy potential, and at the production stage in identifying a reservoir's response to drilling and extraction.

The isotope techniques themselves provide an accurate, and sometimes unique, method for determining the origin of geothermal fluids as well as for tracing water movement. Environmental isotopes like O-18, H-2, H-3, C-13, C-14, S-34, Sr-87, B-11, He-3/H-4. and artificial radioactive tracers such as I-131, I-125, H-3. used in combination with geochemical and geophysical techniques, are very effective in evaluating the energy potential of the prospect, characteristics of the fluids, subsurface processes, reservoir temperatures and properties of the reservoir at exploration stage and in identifying the response of the reservoir to exploitation at production stage.

Origin of fluids and subsurface processes. Stable isotopes indicate the source where fluids have originated (meteoric/connate /magmatic) and altitude of recharge in case of meteoric origin and subsurface processes like rock-water interaction, mixing of shallow groundwater, etc. The naturally occurring radioactive isotope of hydrogen(H-3, tritium) can indicate the presence of cold, young, meteoric water in the geothermal system.

Age/ residence time. The naturally occuring radioactive isotope of hydrogen (H-3, tritium) and carbon (C-14) indicate the age/circulation time of geothermal water.

Temperature. Fractionation factor of stable isotopes in different species in equilibrium depends on temperature therefore isotope geothermometers like O-18(H_2O-SO_4), C-13(CH_4-CO2), H-2(H_2O-H_2) provide estimates of reservoir temperature.

Flow. Artificially produced radioactive tracers such as I-131, I-125, H-3. provide information on the movement of injected fluid, especially breakthrough time, residence time distribution and reservoir characteristics.

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Cultivating better crops for sustainable agriculture

A project of the Regional Cooperative Agreement for Research, Development and Training in Nuclear Science and Technology in Asia and the Pacific (RCA)

The RCA is helping countries in Asia and the Pacific acquire nuclear technologies to breed new varieties of crops with higher yield rates, greater resistance to drought, salinity, disease and pests, and improved quality for consumption. This much-needed boost to agriculture is a timely response to the region's rising demand for food. It will also increase the production of high-value crops such as biofuels for domestic and export markets, and it could make a difference to thousands of smallholder farmers seeking a more sustainable livelihood.

In many parts of Asia and the Pacific, agriculture is beset with difficulties. Rapidly-changing weather patterns over recent years have frequently precipitated floods and droughts. Inappropriate farming practices, deforestation and poor water management blight the earth by eroding top soils and increasing salinity. Yield levels of many traditional crops have reached their limit. And for the region's innumerable subsistence farmers with small landholdings, a bad season doesn't just mean loss of income, it threatens their very existence. Add to these factors the effects of global warming, which are predicted to encourage the spread of pests and disease to new areas, and the outlook for agriculture is challenging to say the least.

Young scientists on an RCA field trip to the sorghum mutant trail in Beijing, China. Sorghum mutants with good tolerance to drought and salinity were developed using nuclear radiation mutation techniques in China and Indonesia. Sorghum mutant germplasms were also exchanged through the Mutant Germplasm Network.

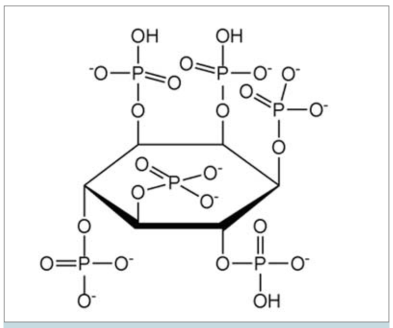
In response to these challenges, the RCA established a project to transfer advanced nuclear, chemical and biotechnological techniques to Member States to assist them in breeding improved food, pulse and oil crops quickly and efficiently. Importantly, an agricultural 'gene bank' - the Mutant Germplasm Network - has also been established in the region. Germplasms (or genotypes) of promising new crop varieties are deposited into this gene bank and preserved. Subsequently they can be drawn on by any country in the network.

Collaboration has been instrumental to the success of this RCA project. As well as establishing a common pool of genetic material through the germplasm network, participating countries have been exchanging research results and sharing insights into how to improve plant breeding techniques. They have also been assisting each other in field-testing crop mutant varieties outside those varieties' countries of origin. For example, a variety of soybean native to Vietnam has proved suitable for growing in Thailand, where it consistently outperforms local varieties. These trials have shown that non-native crop varieties with superior characteristics may retain those characteristics despite being transposed to different environmental conditions. Several of these non-native varieties have been identified for commercial release.

Soybean crinkle leaf disease is a major problem in Thailand, where no native varieties of soybean are resistant to it. Scientists have succeeded in irradiating soybean germplasm with gamma rays to develop several new varieties which are not only resistant to the disease but also high yielding.

Experimenting with plant breeding is nothing new. People have been cross-breeding plants to produce better-performing varieties for many years. In fact, most major crop varieties grown today have at some point in their history been crossbred. But traditional cross-breeding is a slow process, taking several (plant) generations to achieve the desired results. Much quicker results are produced by induced mutaion techniques.

Mutation-breeding by irradiation works, in essence, by accelerating the natural processes of evolution. When living organisms reproduce, they do so imperfectly. Genetic code, as it passes from one generation to the next, mutates slightly - and randomly - in a process known as mutagenesis. This introduces greater diversity into the gene pool, increasing a species' chances of survival. Some mutations are 'successful', surviving to establish themselves over many generations as new varieties (or even new species) - according to Darwin's principle of 'natural selection'.



Phytic acid, found in many cereals, soybean and other legumes, can form anti-nutritional compounds that make these foods indigestible. Research has shown that the presence of two genes significantly reduces phytic acid content. Two new crop varieties containing these genes have now been developed and yield tested. The germplasm can be used to greatly improve the nutritional quality of several crops.

Ionizing radiation (such as gamma rays) increases the rate at which genes mutate. Irradiate a thousand seeds of wheat, for example, and you generate many different mutations-you diversify the gene pool. Some of these mutations may be found to be more resistant to a particular disease, or more tolerant of drought or salinity, or have a higher yield potential. Careful screening and selection of the best performing mutations leads to the development of new plant varieties. This process should not be confused with the production of GM crops, which have been manipulated with foreign genes from other species to enable the crops to acquire specific characteristics. Mutation breeding, in contrast, only accelerates natural changes of its own genes and does not involve cross-species transport of genes.

Through regional training courses, expert missions, group technical visits, and open lecture sessions involving extensive interaction with leading researchers from institutes around the world, countries participating in this RCA project have acquired the skills and technology to conduct their own mutation-breeding programmes. Several high-performance varieties of soybean, groundnut, mungbean, wheat and sesame - some of the region's most important crops - have already been released onto market, and a number of other

Salinity is a serious problem in South-east Asian countries in crop production; and groundnut, an important oil crop in the region, is highly susceptible to it. Dozens of groundnut mutant lines which consistently show improved tolerance have been developed and field tested.

new crop varieties are being field-tested prior to commercial release. China and Indonesia, for example, have developed drought-tolerant wheat and sorghum; India and Sri Lanka have developed high-yielding and early-maturing groundnut; Korea has produced no-shattering sesame and easy-cooking soybean; and Pakistan virus-resistant mungbean.

Together, participating countries are now steadily improving the efficiency of radiation-induced mutations, chemical mutagens and new mutagens, as well as the efficiency of mutant selection processes. The importance and potential of the technology is well illustrated by the fact that today, roughly 10% of all agricultural land in China is cultivated with new varieties of rice, wheat, corn, and cotton that were developed through radiation mutation techniques.

By 'cross fertilising' ideas as well as genotypes, this RCA project has sown the seeds of an agricultural breakthrough that is increasing biodiversity and reducing the time and effort usually required to improve yields and crop quality. Above all, it will help the region develop a sustainable response to the ongoing challenges of population growth, declining land and water resources, drought and salinity, and global warming and climate change.

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Strengthening skills in NDT for regional industry

A project of the Regional Cooperative Agreement for Research, Development and Training in Nuclear Science and Technology in Asia and the Pacific (RCA)

If there's a flaw in your flange, a crack in your casting, or a weakness in your weld, non-destructive testing (NDT) will find it-without damaging or in any way compromising the usefulness of the structure or component being inspected. Over the last 40 years NDT techniques have become an essential part of quality assurance in the construction and manufacture of critical plant and equipment for key industries, and in many countries a mandatory requirement in ensuring the standard of industrial goods. NDT techniques are also widely used in regular maintenance procedures, to assess the reliability and safety of structures subjected to heavy loads, high pressure and corrosion. But for many years, reliable NDT services were not available in most RCA Member States, unless acquired from other parts of the world at great cost. Thanks to a series of RCA projects, local NDT capabilities and expertise are now firmly established in the region, thus providing an important technological tool for the advancement of the region's industrialisation.

NDT techniques use penetrating gamma-rays or X-rays (and other complementary techniques like Ultrasound, Eddy Current, Magnetic Particles etc.) to examine the internal features of a material or product, including any defects it may have. It's similar to the way an X-ray machine in hospital is used to 'see' if a patient has a broken bone. But reliable results from NDT can only be obtained if the technology is handled by well-trained technicians. Prior to 1980, very few countries in Asia and the Pacific had personnel with the necessary training, qualification and expertise, and regional industries were faced with a choice between employing inadequately trained local NDT technicians or hiring NDT services from overseas at higher cost. Some chose neither option and instead exposed critical plant and equipment to the possible risk of failure by not having them inspected at all.

Radiographic testing of a repaired wicket gate of the Samanala Hydro Power Station of Sri Lanka

In response to this unsatisfactory situation, the RCA, with support from the International Atomic Energy Agency, initiated a long-running project in 1981 to build NDT capacity locally. Adopting a highly efficient 'pyramid' training strategy, the RCA first ran a series of regional training courses, using international experts to instruct select groups from participating Member States in various NDT methods and at various levels of expertise. A total of 300 personnel from 14 Member States were successfully trained. In turn, these individuals provided training within their respective countries, disseminating NDT knowledge and technology at the national level. Amongst those trained were engineers, technicians and scientists, some of whom went on to establish NDT facilities and inspection teams within their own organisations. As a result, industry has been quick to adopt the technology, and now almost all large-scale and many medium-scale industries are self-sufficient in NDT technology in most of the RCA Member States.

To date, more than 20,000 personnel across the region have been trained and certified in accordance with their respective national standards, which are based on the international standards ISO/IEC 9712 and ISO17024 (General Requirements for Bodies Operating Certification of Personnel). Linking training and certification to national and international standards is crucial for the viability of NDT services because industry needs to be assured of the skills and competency base underpinning the NDT inspection results. If an NDT inspection fails to detect correctly any material or structural flaws or abnormalities, the financial, operational and safety ramifications can be very serious. Member States are also securing the accreditation of their NDT laboratories as per international standards.

Radiographic Testing of Newly Constructed Pipeline in the Philippine Geothermal Power Plant

Regional harmonisation of national NDT qualifications and certification schemes, is another important step in the process. It is expected that by the end of 2010 ninety percent of Member States will be parties to an agreement for mutual recognition of personnel who hold NDT certificates within the region. The ultimate aim is the harmonisation of all personnel certification schemes in the region by 2012. This will not only be a major step forward in terms of achieving international recognition, it will also mean that RCA Member States will play a positive role in the universal acceptance of ISO 9712/ISO 17024.

The growth of local NDT capabilities within the region has resulted in significant improvements in the safety, quality, reliability and productivity of industrial plants. This has not only benefitted construction and manufacturing processes; regular maintenance checks using NDT have extended the service life of many industrial components. Industries that have profited from this include oil and gas, power generation, chemical and petrochemical, automobile, aviation and construction, plus many of the manufacturing industries which rely on exports to developed countries. Considering the anticipated rapid growth of these industries in the region, the benefits of the RCA project could multiply in the future.

In addition to training, the RCA has also initiated research and development programmes for advanced NDT techniques such as digital radiography and computerised tomography. By the end of 2008 four countries are expected to be in a position to train the remaining Member States in these techniques. There are also plans to set up programmes in two- and three-dimensional tomographic imaging of industrial specimens and civil engineering components.

This RCA project has responded to the needs of industry at a time of significant regional industrial growth. It has helped establish and expand the local NDT service industry, and provided many new career and employment opportunities. Some of the trainees have established their own NDT service businesses, while others have been able to use their internationally-recognised skills overseas. In the early 1980s most industries in the region were barely aware of NDT technology. Now the tables have turned. Instead of needing to import NDT expertise, the Member States are now self-sufficient in most NDT techniques and even have the capability and capacity to export their skills both within the region and beyond.

A training session on Industrial Digital Radiography and Computed Tomography, conducted in Mumbai, India.

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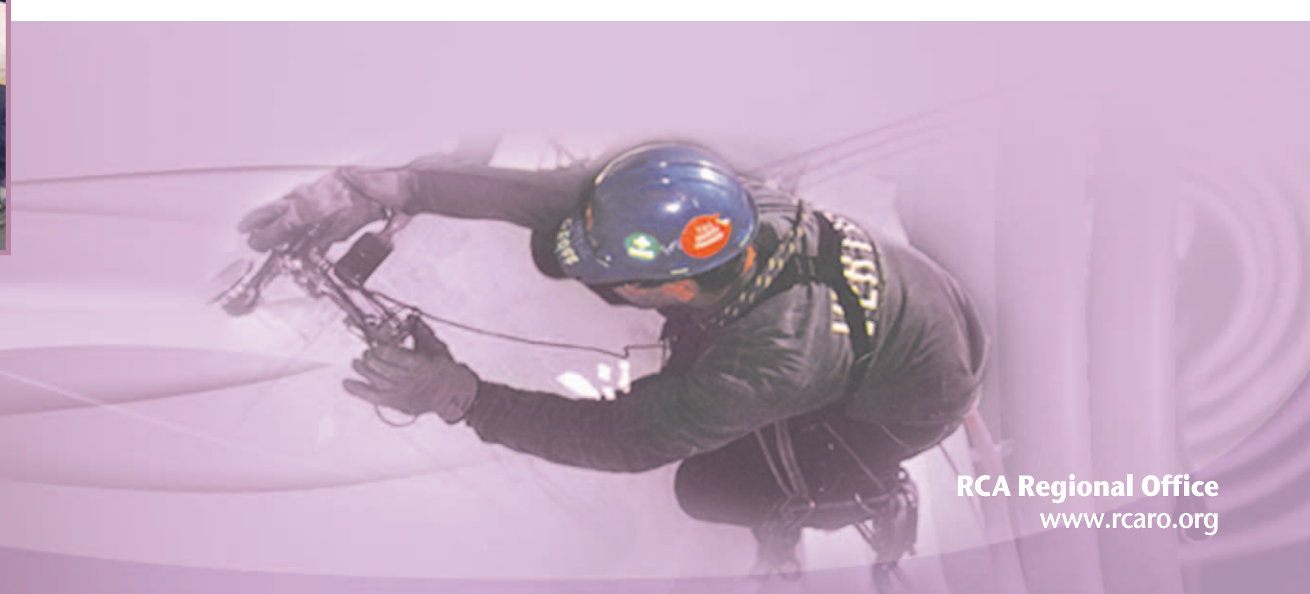

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Turning the tide against marine pollution

A project of the Regional Cooperative Agreement for Research, Development and Training in Nuclear Science and Technology in Asia and the Pacific (RCA)

A recently completed RCA project to bring sophisticated hydrological and ecological risk assessment technologies and techniques to countries in Asia and the Pacific has greatly improved the region's capacity both to deal with pollution in coastal waters and to predict and respond to aquatic ecological emergencies. Not only will these new skills assist Member States in their battle to reduce damage to coastal ecosystems, they will contribute to improving the health of local communities who subsist on aquatic foods and to revitalising their fishing and other marine industries.

All too frequently pollutants entering rivers, lakes and oceans are the by-products of human activity, with aquatic environments being used as dumping grounds for waste materials. This problem has been exacerbated in recent decades by the growth of mining and other industries in East Asia and the Pacific. Substantial arsenic deposits, for example, have accumulated in the sediments of the Mekong Delta. But pollution does not arise only from anthropogenic sources. Pollutants also enter the water from natural sources, especially when there are earthquakes and volcanic eruptions or severe climatic or geological events such as cyclones and tsunamis.

BATAN staff inject the radiotracer technetium-99m into a river entering Jakarta Bay. The survey boat follows the technetium tracer as it travels through the water.

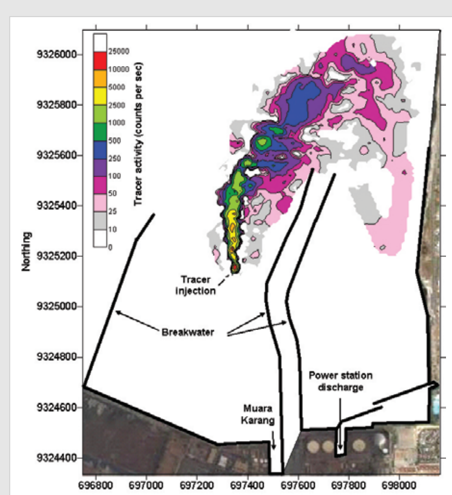
Conventional techniques for tracing pollutants and contaminants are of limited use in the muddy, organic-rich waters typical of the RCA region. This is due to the large background signal from natural fluorescing substances as well as to the rate of dilution and dispersion that occurs with increasing distance from the injection point. Nuclear tracer techniques, on the other hand, are more sensitive, more selective and have greater ease of detection. Highly accurate and specific information on ecological, physical, chemical and biological processes may be obtained by selection of proxy isotopes with the appropriate properties. The nuclear tracers used may be naturally-occurring isotopes characteristic of the particular process under investigation, artificial and introduced as analogues of natural products, or labels on substances retrieved from nature.

Although the winds, tides and currents – Nature's own 'rubbish removers' – disperse many of these water-borne pollutants when they reach the ocean. They are no match for the levels of pollution in evidence today. Populations of fish, seaweed and other aquatic flora and fauna are being decimated, and toxins are entering the food chain. High concentrations of toxins are now found in the water and in aquatic foods which form the staple diets of coastal communities. As well as impairing the health of these communities, toxins damage their economies by contaminating the fish, crustaceans and other aquatic food resources in which they trade.

It became clear that RCA Member States needed to acquire advanced technologies to help in the study of these pollution problems and to assist in improving their capabilities to respond to and manage potential emergencies. Between 2003 and 2006 the RCA therefore ran a project, funded by Australia and implemented through the International Atomic Energy Agency's technical cooperation programme, to provide these technologies and skills.

Through a series of regional training courses and national workshops, local hydrologists and ecologists learnt to use the most advanced conventional and nuclear tools and techniques to sample and analyse the composition, movement and impact of water-borne pollutants and contaminants. With these capabilities they can now accurately determine the severity of pollution in drinking water, the effect of contaminants on aquatic organisms, and the concentration of toxins in aquatic food resources and consequently their suitability for human consumption.

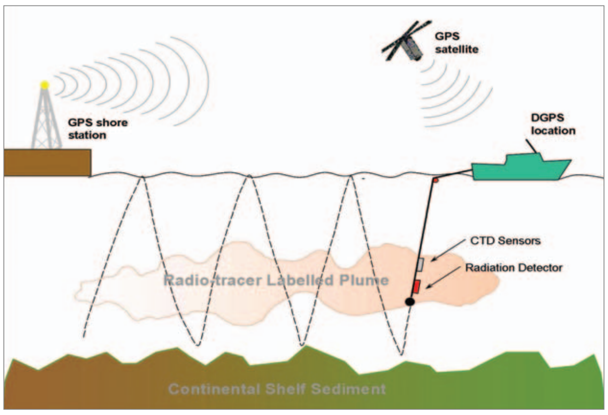
Participating countries also formed their own national project teams which, under the guidance of international experts, conducted local projects to map the movements of pollutants through specific estuarine, coastal lake and riverine environments. From this data, and using probabilistic risk assessment modelling software, they developed computer-simulated models of the local waterways. With these hydrodynamic models they can predict, and respond to, the likely ecological consequences of, for example, the release of an industrial effluent into the ocean, or the construction of a new wharf in a river.



The compiled tracer survey data show the movements of the river as it empties into Jakarta Bay over a 5-hour period.

Finally, in a series of simulated aquatic crises, programme participants were given the challenge of developing emergency response plans to various pollution scenarios. These simulations gave Member States valuable experience in developing fast and effective responses to all kinds of marine emergencies, whether from the spread of algal blooms, the spillage of hazardous chemicals, or contamination by radioactive substances.

As well as disseminating a range of skills and strategies that will serve project participants well into the future, this RCA initiative has generated considerable interest amongst marine research institutes and environmental management agencies. Several of these organisations are now



collaborating with Member States' nuclear agencies, and are learning and applying the isotopic risk and response technologies in their own localities. Skill- and knowledge-sharing networks are beginning to flourish. Thus in the battle against marine pollution, which knows no boundaries, a 'borderless' region-wide response has been set in motion.

As part of this RCA project, a major demonstration of nuclear analytical techniques was undertaken at Jakarta Bay in Indonesia, as a model for other Member States to follow. Jakarta Bay is an ecologically-threatened site, and typical of other bays in the region. Its marine ecosystems have been polluted by industrial activities in the upper catchment and offshore areas as well as by local domestic and commercial activities.

First, a three-dimensional hydrodynamic contaminant transport model and mathematical model of the Bay were developed. Then, a programme of field work was devised, which included a series of radioisotope experiments carried out in specific locations in the Bay. This field work was carried out jointly by Australian and Indonesian teams. The results were then used by experts to validate and calibrate the mathematical model. The outcome is a highly accurate hydrological tool and knowledge-base to assist the local Indonesian agencies in the ongoing environmental management of Jakarta Bay.

The work was carried out by the Indonesian National Project Team with the assistance of experts from the Australian Nuclear Science and Technology Organisation and the University of New South Wales Water Research Laboratory. Integral to the success of the demonstration was the participation also of the Indonesian Nuclear Agency (BATAN) and several key end-users including the Indonesian Institute for Sciences (LIPI) Research Centre for Oceanography, the Bandung Institute of Technology (ITB), and the Jakarta Metropolitan Environmental Management Agency.

Having worked on this demonstration project, the Indonesian Team now has the skills and experience to carry out similar studies and respond to major pollution events elsewhere in Indonesia. They also now act as a regional resource, advising and assisting other Member States carrying out similar studies.

The Jakarta Bay demonstration offers an example of good practice strategy for ecological risk assessment using hydrodynamic model development, model validation using radiotracers, and a contaminant ecotoxicology database specific to organisms native to the region. The strategy and outcomes were disseminated to other RCA countries at a regional training course in China in late 2006.

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