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Front Cover: Ten years after the tragic accident in April 1986 at the Chernobyl nuclear power plant in Ukraine, the consequences are still being debated. In many cases, speculation clouds public perceptions and obscures the factual scientific record. In this edition of the *IAEA Bulletin,* feature articles examine aspects of the post-Chernobyl nuclear picture, including nuclear power's development and future in many countries and the sharper global focus on issues of nuclear and radiation safety. A forthcoming edition will report on the outcome of an International Conference at the IAEA in April 1996 that will sum up the known radiological consequences of the Chernobyl accident.
(Cover design: Hannelore Wilczek, IAEA; Stefan Brodek, Vienna.)

Facing Page: On a scientific expedition, scientists at the IAEA's Marine Environment Laboratory in Monaco collect samples on the high seas. Their work following the Chernobyl accident contributed significantly to the world's understanding of the radiological impact on the marine environment. *(Credit: IAEA-MEL)*

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Nuclear power beyond Chernobyl: A changing international perspective

Nuclear power's development has slowed over the past 10 years but steady growth is projected well into the next century

by
Poong Eil Juhn
and Jürgen
Kupitz

Statistics show that nuclear power has become an important energy source in many countries since its introduction four decades ago. In the 1960s, the industry was convinced that nuclear power represented the solution to cheap and reliable energy supply, and programmes were eagerly pursued worldwide. As a result, the construction of nuclear power plants expanded rapidly through the 1970s. According to data in the IAEA's Power Reactor Information System (PRIS), by 1980 nuclear power production had increased to 692.1 terawatt-hours (TWh), contributing 8.4% of total electricity generation. *(See figures, next page.)* This represented an almost ninefold increase since 1970, and an average annual growth of 24% over the decade.

Since the 1980s, the expansion rate has dropped markedly even though significant new nuclear electricity capacity is still added each year. In the period 1980-85, nuclear electricity generation increased to 1402 TWh, corresponding to an average annual growth of 15.2% in generation; in the next half decade, during 1985-90, it increased to 1913 TWh, yielding an annual growth of 6.4%. In the period 1990-94, it increased to 2130 TWh, corresponding to a growth of about 2.8% per annum. The five largest producers in 1994 were the United States (639.4 TWh), France (341.8 TWh), Japan (258.3 TWh), Germany (143.0 TWh), and Canada (101.7 TWh).

Worldwide, the nuclear option today accounts for about 17% of the total electricity produced. In altogether 14 countries (as well as in Taiwan, China), one-quarter or more of the electricity is generated by nuclear power plants. Nuclear power accounts for some 40% or more in eight countries: Belgium, Bulgaria, France, Hungary, Lithuania, Slovakia, Sweden, and Switzerland. *(See the International Data File section, page 53.)*

By the end of 1995, a total of 437 units with a generating capacity of over 343 gigawatts-electric (GWe) were in operation in the world, and 39 units with a generating capacity of over 32 GWe were under construction. The total accumulated operating experience of the operating plants amounts to more than 6637 reactor years, or an average operating period per plant of about 15 years. Substantial operating experience has also been gained by plants that have now been shut down, and factoring in these plants yields a total of more than 7700 reactor years. In other words, by now, nuclear energy has acquired a strong position in the electricity generation sector as a mature technology.

Impact of the Chernobyl accident

Recent development trends could give the impression that nuclear power's slower rate of growth after the 1985-90 period is mostly due to the Chernobyl accident, which occurred in April 1986. Actually, other factors were at work as well, and overall Chernobyl's impact varied around the world.

One factor has been the rate of electricity growth, which in many countries declined during the past decade and influenced decisions about capacity additions throughout the electricity sector. Since the construction of a nuclear plant takes 5 to 8 years to complete, with a lead time (after contract) of 1 to 2 years, any observable indication of Chernobyl's direct impact over the past decade would be hard to discern.

Still, the accident did have immediate consequences in some countries. In countries operating Chernobyl-type reactors, the operation of the plants was carefully checked and a number of restrictions were imposed. Public opposition also caused other types of plants outside these coun-

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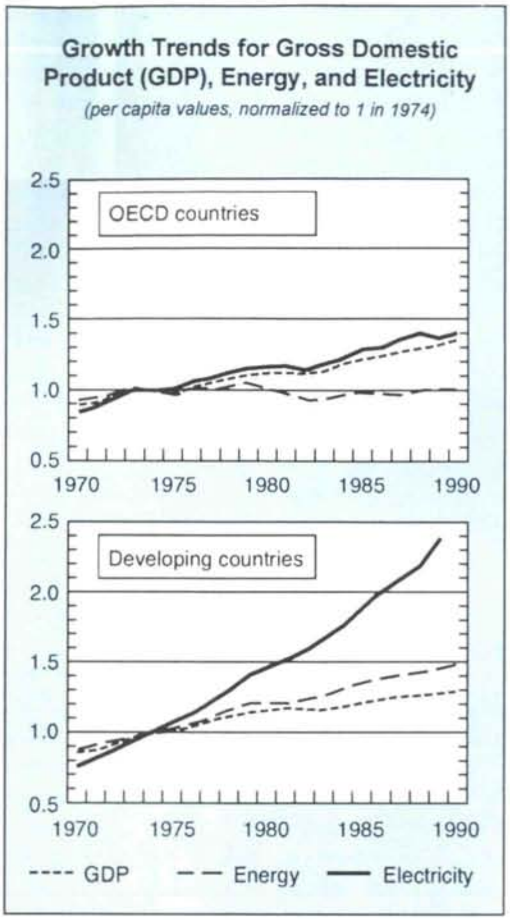

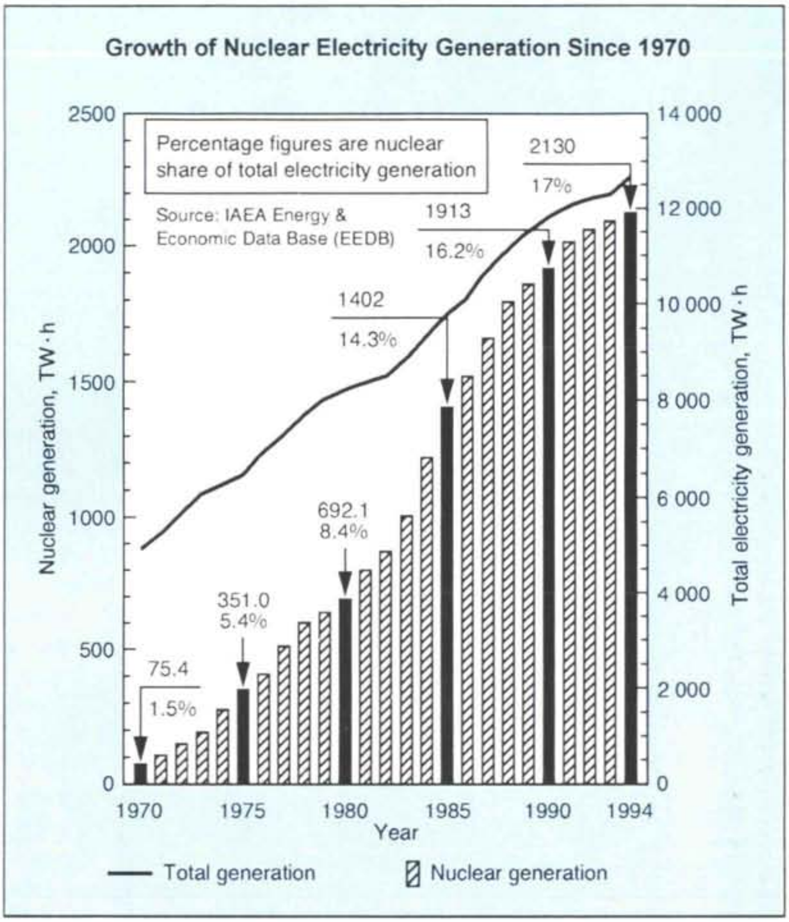

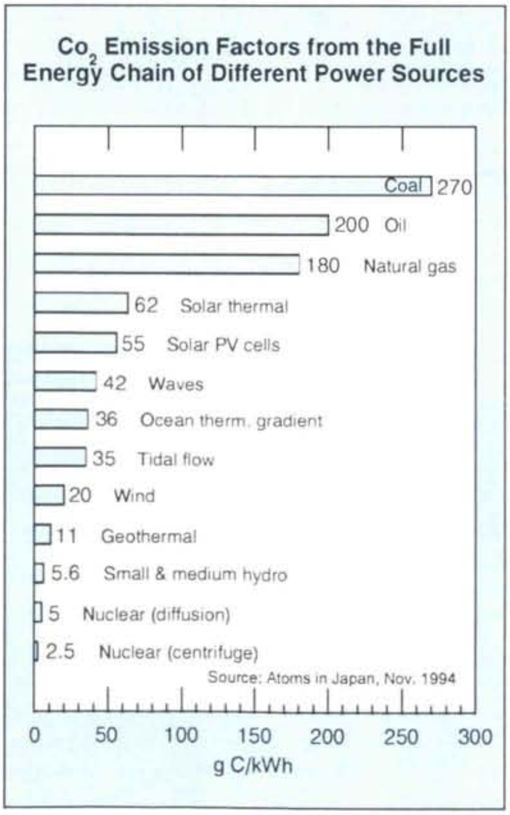

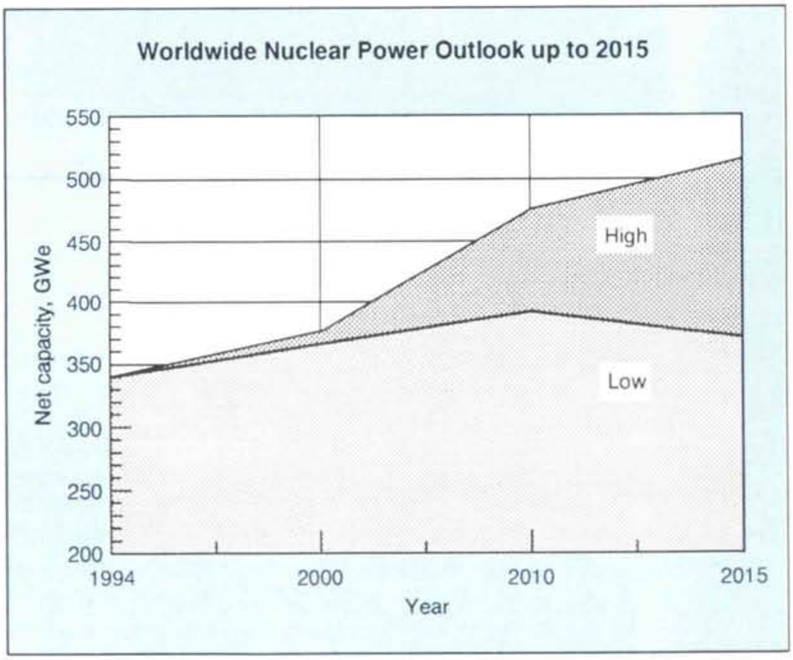

Nuclear power's growth has slowed markedly over the past two decades, though steady development continues. Environmental concerns are driving renewed interest in nuclear-generated electricity, a low CO_2 option.

tries to shut down for a period of time. In Italy, the Caorso plant was taken out of service indefinitely and construction of the Montalto di Castro plants was stopped following a referendum in the wake of the accident, and in both Finland and the Netherlands plans for new nuclear power plant projects were mothballed.

Generally in Europe, the Chernobyl accident is one of the reasons that increases in nuclear deployment have been brought more or less to a complete halt; politicians do not dare to promote nuclear power as a safe and clean energy source, and utilities are afraid of the financial risks with respect to the economic consequences of a major nuclear accident. Besides, the economies of the European countries have been growing at a very slow rate, if growing at all, and the rate of growth in overall energy demand has been very small. On the other hand, recent studies have shown that the picture is likely to change. Electricity consumption continues to rise with economic growth, even when total energy consumption is decreasing. In a few years time more generating capacity will be needed in many countries, and chances are that some of this additional capacity will be nuclear power plants.

In regions of Asia, the situation is different; the rate of growth in energy demand is very high and nuclear is seen as an attractive option. Many countries in these regions have ambitious programmes for deployment of nuclear power in the next decades, and vendors worldwide are anticipating a revitalization of the nuclear market.

Advanced nuclear power plant designs

In a number of countries, great emphasis is being placed on the development of advanced nuclear power plant designs. These new generations of nuclear power plants have been, or are being, developed by building upon experience and applying lessons learned from existing plants. Hence, the new, advanced designs are anticipated to become even more safe, economic, and reliable than their predecessors.

The advanced designs generally incorporate improvements of the safety concepts, including, among others, features that will allow operators more time to perform safety actions, and that will provide even more protection against any possible releases of radioactivity to the environment. Great attention is also paid to making new plants simpler to operate, inspect, maintain, and repair, thus increasing their overall reliability and economy.

Advanced designs comprise two sub-categories: evolutionary and developmental designs. The first encompasses direct descendants from predecessors (existing plant designs) that feature improvements and modifications based on feedback of experience and adoption of new technological achievements. They also take into account possible introduction of some new features, e.g., by incorporating passive safety functions. Evolutionary designs are characterized by requiring, at the most, engineering and confirmatory testing prior to commercial deployment. Developmental designs consist of those that deviate more significantly from existing designs, and that consequently need substantially more testing and verification, probably including also construction of a demonstration plant and/or prototype plant before large-scale commercial deployment.

Advanced designs under development comprise three basic types: water-cooled reactors, utilizing water as coolant and moderator; fast reactors, using liquid metal, e.g. sodium, as coolant; and gas-cooled reactors, using gas, e.g. helium, as coolant and graphite as moderator.

Most — about 75% — of the nuclear power reactors in operation are water-cooled reactors, and most of the advanced designs are, too. They are of two basic types: light-water reactors (LWRs) with ordinary water as moderator, and heavy-water reactors (HWRs). The LWRs are in turn subdivided into boiling and pressurized water reactors (BWRs and PWRs).

Some examples of large evolutionary advanced LWRs are: the ABWR of General Electric, United States; the APWR of Westinghouse, United States and Mitsubishi, Japan; the BWR-90 of ABB Atom, Sweden; the EPR of Nuclear Power International (NPI), a joint company of Framatome in France and Siemens in Germany; the SWR (or BWR) 1000 of Siemens; the System 80+ of ABB Combustion Engineering, United States; the WWER-1000 (V-392) of Atomenergoproject and Gidropress, Russia; and the KNGR of KEPCO and KAERI, the Republic of Korea. Among the medium-size ALWRs, five typical designs are the AP-600 of Westinghouse, United States; the AC-600 of China National Nuclear Corporation, China; the MS-600 of Mitsubishi, Japan; the SBWR of General Electric, United States; and the WWER-640 (V-407) of Atomenergoproject and Gidropress, Russia. Many of the large- and medium-size designs are already available for commercial deployment, or will be within a number of years.

The situation for developmental designs — such as ISIS of Ansaldo, Italy; PIUS of ABB Atom, Sweden; SPWR of JAERI and IHI, Japan; and VPBER-600 of OKBM, Russia — is more uncertain. This is due to the need for experimental verifications and associated financing burdens.

Typical examples of advanced HWRs under development are the advanced Canadian designs — Candu-3 (of about 450 MWe), the Candu-6 (currently of about 680 MWe), and the Candu designs (of 900-1100 MWe) of AECL, Canada — and the improved Indian PHWR design (of about 500 MWe).

Liquid metal-cooled fast reactors (LMFRs), or breeders, have been under development for many years in a number of countries. The design, construction, and operation of several plants, such as the BN-600 in Russia, the 1200-MWe Superphenix in France, and the 280-MWe Monju in Japan, has provided extensive experience of more than 200 reactor years for further improvements. The fast reactors use "fast" neutrons for sustaining the fission process, and they actually produce fuel as well as consume it; plutonium breeding allows fast reactors to extract sixty times as much energy from uranium as thermal reactors do. Their capability of producing fissile material may become indispensable in the longer term if the deployment of nuclear power is increased substantially in the decades to come. Fast reactors may also contribute to burning of plutonium and to reduction of the required isolation time for high-level radioactive waste by burning of long-lived transuranic radioisotopes.

The further development of fast reactors focuses on improving plant safety and economy, and on improvements of fuel burnup and fuel recycling technology to reduce the amounts of radioactive waste. Examples of development concepts are the BN-800M in Russia, the DFBR in Japan, the PFBR in India, the advanced European EFR, and the LMR developed by General Electric in the United States.

Gas-cooled reactors have been in operation for many years. In the United Kingdom, nuclear electricity is mostly generated in CO_2-cooled Magnox and Advanced Gas-Cooled Reactors (AGRs). Other countries also have pursued development of high-temperature reactors (HTGRs) with helium as coolant, and graphite as moderator. Prototype or demonstration plants have been built, without complete success, however. The inert helium gas and a special fuel design enable these plants to operate at temperatures considerably above those in water-cooled reactors; hence, they can supply steam for conventional steam turbine generators at much higher temperature (and pressure), or high-temperature process heat for special applications.

Further HTGR development concentrates on improved plant performance and life extension studies. In particular, much effort is devoted to the direct gas-turbine cycle which may yield very high thermal efficiency and low energy cost. A demonstration plant for testing of high temperature process heat applications is under construction in Japan, and construction of a test reactor has begun in China.

Prospects for nuclear power

Nuclear power alone will not ensure secure and sustainable electricity supply worldwide, nor will it be the only means of reducing greenhouse gas emissions, which continue to be a major environmental concern. But it has a key role to play. Studies of greenhouse gas emissions from different energy chains for electricity generation indicate that nuclear power is one of the cleaner options. *(See graphs.)*

A prerequisite for realizing the necessary revival of the nuclear option is that the technical and economic performance of nuclear power plants must improve. At the same time, plant safety must be further enhanced and the issues of waste management and disposal must be more satisfactorily addressed.

At the present time, nuclear power is among the cheapest sources of electricity generation in many countries. Its competitive margin has been reduced, however, by low fossil fuel prices and increases in nuclear power plant capital costs, which are very much due to long construction and licensing lead times. Rising market prices of fossil fuels, in particular gas, and increased capital and operating costs of fossil fired units due to the required addition of abatement systems for environmental reasons may reverse this trend in the coming decade. The economic advantage of nuclear power can further be increased by the efforts of reactor designers to reduce capital costs by streamlining the reactor concepts, reducing the amount of material required, and shortening the construction times. Substantial progress has been achieved in this regard and additional gains are expected through the deployment of advanced reactors.

Financing nuclear power plants will remain a key issue, especially in developing countries. Technology adaptation, the development of small- and medium-size reactors, and the implementation of new financing approaches may alleviate funding constraints and facilitate a broader deployment of nuclear power.

Nuclear power projections beyond 2000

Projecting nuclear power development is a somewhat difficult exercise. A number of factors can influence policies and decision-making, and the implementation of programmes cannot be assessed with certainty.

Up to the year 2000, the installed nuclear capacity worldwide will grow to between 367 GWe and 375 GWe, compared to 340 GWe in 1994, according to IAEA estimates. Since all the units to be commissioned by the turn of the century are already under construction, the range of uncertainty reflects potential delays in construction and licensing. New nuclear units will be connected to the grid mainly in Asia, while in Western Europe and North America the installed nuclear capacity will remain practically unchanged. In Eastern Europe, although some of the units under construction will be completed, the economic transition will delay significantly the implementation of nuclear programmes in most countries.

After the turn of the century, the range of uncertainty regarding nuclear power development is wider, owing to a number of technical, economic, environmental, and policy factors. The low and high projections for nuclear generating capacity developed by the IAEA up to 2015 are based upon a review of nuclear power projects and programmes in Member States. They reflect contrasting but not extreme underlying assumptions on the different driving factors that have an impact on nuclear power deployment. These factors and the ways they might evolve vary from country to country. Consequently, the IAEA projections do not reflect the whole range of possible futures from the lowest to the highest feasible, but provide a plausible range of nuclear capacity growth by region and worldwide.

In the low case, the current barriers to nuclear power deployment are assumed to prevail in most countries during the coming two decades. Economic and electricity demand growth rates remain low in industrialized countries. Public opposition to nuclear power continues, and environmental concerns, such as the risk of global climate change, do not become strong driving factors in energy policies to switch from fossil to nuclear energy. Institutional and financing issues prevent the implementation of previously planned nuclear programmes, in particular in countries in transition and in developing countries, and there is no drastic enhancement regarding nuclear technology adaptation and transfer, nor financial support to developing countries for the implementation of nuclear power projects.

Under these rather pessimistic assumptions, most of the nuclear units under construction would be completed but new nuclear units would be ordered only in the countries where nuclear power is a major component of electricity generation mixes, such as France, Japan, and the Republic of Korea. Owing to the large number of units that would be shut down at the end of their scheduled operating lifetime, the total nuclear capacity in the world would start to decrease after 2010 and would be similar in 2015 to that in 2000, i.e., at some 370 GWe. The share of nuclear power in world electricity supply would decrease from about 17% at present to some 13% in 2015.

The high case reflects a moderate revival of nuclear power deployment, that might result in particular from a more comprehensive comparative assessment of the different options for electricity generation, integrating economic, social, health, and environmental aspects. This case assumes that some policy measures would be taken to facilitate the implementation of these programmes, such as strengthening of international co-operation, enhanced technology adaptation and transfer, and establishment of innovative funding mechanisms. Based on these assumptions, the total installed nuclear capacity worldwide would reach some 515 GWe in 2015 and the share of nuclear power in total electricity generation would be some 15%.

In both the low and high cases, the production capabilities of the world nuclear industry would exceed the demand for new reactors. A higher rate of nuclear power development would be technically feasible and economically viable in a number of countries. However, a substantive revival of nuclear power programmes would require policy measures, including a removal of the *de facto* moratoria in several countries and the introduction of mechanisms for providing funding support to nuclear projects in developing countries, which seem unlikely to be implemented in the short term.

Other applications of nuclear energy

Today, only a few nuclear plants are being used for non-electric applications (with a total capacity of only 5 GWth to supply hot water and steam). The potential market for applications of nuclear energy in the non-electric energy sector may be quite large, however. About 30% of the world's primary energy consumption is used for electricity generation, about 15% is used for transportation, and the remaining 55% is converted into hot water, steam, and heat. Non-electric applications include desalination, hot water for district heating, and heat energy for petroleum refining, for the petrochemical industry, and for the conversion of hard coal or lignite.

For non-electric applications, the specific temperature requirements vary greatly. Hot water for district heating and heat for seawater desalination require temperatures in the 80° to 200°C range, whereas temperatures in the 250° to 550°C range are required for petroleum refining processes. The use of heat for enhancing heavy oil recovery can be applied by the method of hot water or steam injection. The temperature and pressure conditions required for heavy oil recovery are highly dependent on the geological conditions of the oil field; the temperature requirements range up to 550°C and above. Oil shale and oil sand processing requires temperatures ranging from 300° to 600°C, and processes used in the petrochemical industry require higher temperatures, in the range of 600° to 880°C. Still higher temperatures (up to 950°C) are needed for refining hard coal or lignite (for example, to produce methanol for transportation fuel), and temperatures of 900° to 1000°C are necessary for the production of hydrogen by water splitting.

Water-cooled reactors can provide heat up to about 300°C, and liquid-metal-cooled fast reactors produce heat up to about 540°C. The gas-cooled reactors can provide even higher temperatures, about 650°C for advanced gas-cooled, graphite-moderated reactors (AGRs), and up to 950° to 1000°C for high-temperature gas-cooled reactors (HTGRs).

There is considerable incentive to utilize the capability of nuclear plants to provide co-generation of electricity, steam, and heat for residential and industrial purposes. Experience in co-generation with water-cooled reactors has been gained in the Russian Federation, China, Canada, the Czech Republic, Slovakia, Switzerland, Germany, Hungary and Bulgaria. One of the largest uses of nuclear process steam is at the Bruce Nuclear Power Development Facility in Ontario, Canada, where the Candu PHWRs are capable of producing 6000 MWe of electricity as well as process steam and heat for use by Ontario Hydro and an adjacent industrial energy park.

An important milestone in the development of high-temperature nuclear process heat was reached in March 1991 with the start of construction of the HTTR (High Temperature Engineering Test Reactor) at the Oarai Research Establishment of the Japanese Atomic Energy Research Institute. It will be the first nuclear reactor in the world to be connected to a high-temperature process heat utilization system.

Nuclear power in developing countries

Most nuclear power plants are located in industrialized countries, but a number of developing countries also are relying on the nuclear power option. At the end of 1995, there were 73 nuclear units (or about 16% of the total number in the world) with a net capacity of close to 45 GWe (about 13% of total worldwide capacity) in operation in developing countries. The accumulated operating experience of these plants amounts to 850 reactor years, corresponding to an average of 11 years of operation per plant.

This means that nuclear power already is an established technology in a number of developing countries. The deployment of nuclear power is also expected to expand substantially in the next decade. It can be noted that more than half of the 39 units reported as "under construction" in 1995 were being built in developing countries.

The world's energy demands are expected to rise significantly in the coming decades. The world population has nearly doubled over the last three decades and will continue to increase. Forecasts are that by the year 2020 there will be about eight billion people living on this planet, with some 90% or more of the population increase taking place in developing countries. In these countries, electricity consumption *per capita*, which may be used as an indicator of standard of living, is very low, about one or two orders of magnitude below industrialized countries.

The high cost of building nuclear power plants, however, and financing constraints have become major hurdles for many developing countries. For countries with an existing infrastructure, established nuclear power programmes, and an indigenous manufacturing capability, the situation is not too bad; they need only to import special components, equipment and know-how from abroad, with a corresponding limited spending of foreign currency.

In most developing countries, a suitable infrastructure and manufacturing capability is not available. They generally also have a currency that is not convertible, which means that when they buy most of the plant equipment from abroad, they must depend heavily on loans from foreign banks or institutions.

In this context, it may be noted that when constructing the first nuclear power plant a preferable approach appears to be having a "turnkey" delivery, including a technology transfer programme. In that way, the possibilities of making the first plant project a success, actually a matter of paramount importance for the acceptability of a nuclear programme, would be the best. Additionally, the transfer of technology will enable the country to gradually develop its own capabilities, and successively increase the domestic participation in subsequent nuclear power plant projects.

Some developing countries, such as China, India, and the Republic of Korea, have ambitious programmes for deployment of nuclear power, and are also actively pursuing development of their own reactor designs. China has three nuclear units in operation, of which one is of own

Role of the IAEA in Nuclear Power Development

Advanced Reactor Development. The early development of nuclear power was conducted to a large extent on a national basis. However, for advanced reactors, international co-operation is playing a greater role, and the IAEA promotes international co-operation in their development. Especially for designs incorporating innovative features, international co-operation can play an important role for pooling resources and expertise in areas of common interest to help meet the high costs of development.

The Agency's programme in nuclear power technology development promotes technical information exchange and co-operation between Member States with major reactor development programmes. It offers assistance to Member States with an interest in exploratory or research programmes, and publishes reports which are available to all Member States interested in the current status of reactor development. Activities are focused on key issues (for example safety concerns, high capital costs, complex and expensive operating procedures) which currently hinder further introduction of nuclear power.

IAEA activities in the development of water-cooled, liquid-metal-cooled, and gas-cooled reactors are co-ordinated by three international working groups (IWGs) which are committees of leaders in national programmes in these technologies. Each IWG meets periodically to serve as a global forum for information exchange and progress reports on national programmes, to identify areas of common interest for collaboration, and to advise the IAEA on its technical programmes and activities. This regular review is conducted in an open forum in which operating experience and development programmes are frankly discussed. Smaller specialists' meetings are convened to review progress on selected technology areas in which there is a mutual interest. For more general participation, larger technical committee meetings, symposia, or workshops are held. The IWGs sometimes advise the IAEA to establish co-operative programmes in areas of common interest in order to pool efforts on an international basis. These co-operative efforts are carried out through co-ordinated research programmes (CRPs). CRPs are typically of a duration of 3 to 5 years and often involve experimental activities. Such CRPs allow a sharing of efforts on an international basis to develop technology at a lower cost than would be required with separate national efforts, and to benefit from the experience and expertise of researchers from the participating institutes.

Nuclear Power Plant Personnel Training & Qualification. Agency activities in this area have expanded greatly since 1993. The main focus is the introduction and use of a systematic approach to training (SAT) for plant personnel to enhance their qualification and competence and thus the safety and reliability of plant operation and maintenance. Regulatory bodies in a number of Member States mandate or strongly recommended the SAT approach to the training of nuclear power plant personnel.

An International Working Group on Nuclear Power Plant Personnel Training and Qualification was constituted in 1994 to provide advice concerning IAEA activities in this area and to promote global co-operation. A new type of IAEA assistance on personnel training has been introduced in the form of the Training Advisory Service (TAS). On request from a Member State or nuclear power plant, the IAEA organizes a TAS, which comprises training experts from various countries who would provide technical advice and assistance on all aspects of training, including the exchange of experience and good practices.

Nuclear Power Plant Project Management. The IAEA provides assistance to requesting Member States in a variety of areas related to the use of nuclear power for safe and economic electricity generation. This assistance is directed to national authorities, operating organizations, and the industrial infrastructure that supports the planning and execution of nuclear power project.

An important objective is to assist developing Member States in achieving self-sufficiency in the systematic development and improvement of a wide range of infrastructural facilities, including organizational structures and their management, transfer of tools and methodologies for project management, and the feedback of construction experience from successful project execution.

No less important is the problem of providing qualified human resources to plan, regulate, and implement the nuclear power programme. Thus, programmes are being supported with the objective of creating an independent national training infrastructure that meets the needs of the nuclear industry. To this effect, ten projects for nuclear power programme implementation are being put into service in eight countries in regions of the Middle East, Europe, Asia and the Pacific.

In order to complement assistance provided under individual projects, topical training courses, workshops, and seminars are held on subject matters selected for their relevance to country specific needs and requirements. At the international level major training courses are offered periodically for participants from all regions. These courses are designed to represent an effective transfer of technology that helps create a base of trained personnel in developing countries. They cover subjects such as strengthening project management, quality assurance in nuclear power plant operation and maintenance, qualification of nuclear power plant operations personnel, and control and instrumentation in nuclear power plants.

design, and has ordered another two 950-MWe units from abroad. It also plans construction of a WWER-1000, and is discussing construction of Candus with AECL of Canada. The near-term programme includes serial production of a 600-MWe version of the indigenous PWR design that is in operation at Qinshan, and further development of that type; construction of a heating reactor of its own design at Daqin; and construction of a high temperature test reactor.

India has 10 plants in operation of which six are PHWRs of own design, and another four are under construction. Development activities are concentrated on a 500-MWe PHWR and a 500-MWe fast, sodium-cooled breeder reactor.

The Republic of Korea has 11 units in operation, all supplied by foreign vendors. With its latter units, the country has entered a new era, bringing on line the first of a series of plants based on the System 80 of ABB Combustion Engineering for which more and more design, engineering, and equipment are supplied by Korean companies. Five plants of this series and of another type are under construction, and a further 11 plants are planned for the period up to 2006. Development also has begun on the next generation reactor, with operation targeted for 2006.

Some other developments should also be noted: the supply to the Democratic Peoples Republic of Korea of two PWR plants of Korean Standard Nuclear Power Plant; Indonesia's rather firm plans on introduction of nuclear power within some years; Thailand's interest in nuclear power; the Islamic Republic of Iran's desire to get support for completing the Bushehr units; Pakistan's construction of one 300-MWe PWR and its discussions on the possibilities of having a second such unit built; Morocco's desire to start a feasibility study on desalination of seawater using nuclear-supplied heat; and Egypt's plans on utilization of nuclear power.

In Eastern Europe, Armenia has restarted one of its nuclear plants; the Czech Republic has two units under construction; Romania has four units under construction; the Slovak Republic has four units under construction, and Ukraine has two (with plans for six) units under construction.

In Latin America, Argentina and Brazil each have one unit under construction. Argentina is also developing its own nuclear reactor designs. Mexico has two plants in operation, but no firm plans for further construction; in the early 1980s, it had a very ambitious programme for nuclear power development that had to be abandoned for financing reasons. It can also be noted that Venezuela has been discussing utilization of nuclear power plants for heat and electricity generation; the heat is intended for improving the heavy oil extraction along the Orinoco river.

Challenges and prospects

Prospects for nuclear power should be assessed in the context of growing electricity demand and greater awareness of environmental issues. Nuclear power alone will not solve all the problems, but it will form part of the answers.

Over the near term, nuclear power projects will be pursued mostly in Asian countries, including China, Japan, and the Republic of Korea. In many other regions of the world, safe and reliable operation of nuclear power plants, convincing solutions to high-level nuclear waste storage and disposal, and a predictable licensing process are essential prerequisites for the revival and expansion of nuclear power.

Today, energy consumption trends reflect the important role that electricity plays in modernization efforts and in total energy use and efficiency improvements. Also increasingly evident is that full participation in the information and communication age requires reliable sources of electricity. Studies have shown that there is a distinct correlation between the trends of electricity consumption and national economic output in a wide range of countries. From 1960 to 1990, the share of electricity in global energy consumption has grown from 17% to 30% and the annual consumption of electricity *per capita* has almost tripled (from 765 to 2225 kWh per person). Still, two billion people in the world do not have access to electricity in their homes.

For years ahead, it is quite obvious that *per capita* consumption of electricity in developing countries will have to increase substantially to sustain economic growth and improve standards-of-living. The accelerating movement toward urbanization, which allows easier access to electrical distribution systems, together with the electrification of rural areas, will also contribute to a steadily increasing role for electrical power. In the Republic of Korea, where nuclear power already is a major producer, *per capita* electricity consumption has grown from 70 kWh per year in 1960 to almost 3200 kWh per year in 1992.

Over the next decades, the projected growth in the Earth's population, mostly in developing countries, will place higher demands on energy and electricity supplies. According to the World Energy Council, global consumption of electricity can be expected to increase between 50% to 75% by the year 2020. The potential clearly exists for nuclear power to play an important role as a safe and clean source of electricity to help countries meet their future energy needs. ❐

Safety of RBMK reactors: Setting the technical framework

The IAEA's co-operative programme is consolidating the technical basis for further upgrading the safety of Chernobyl-type reactors

by
Luis Lederman

In April 1986, unit 4 of the Chernobyl nuclear power plant in Ukraine was destroyed in the worst accident in the history of commercial nuclear power. The reactor, which started operation in 1983, was a Soviet-designed nuclear power plant known by the Russian acronym RBMK.

The RBMK evolved from Soviet uranium-graphite reactors whose purpose was the production of plutonium. The first of these plutonium production reactors began operation in 1948. Six years later, in 1954, a demonstration 5-MWe RBMK-type reactor for electricity generation began operation in Obninsk. Subsequently a series of RBMKs were developed using the combination of graphite moderation and water cooling in a channel design.

Today 15 RBMK power reactors are producing electricity in three States: 11 units in Russia, two in Ukraine, and two in Lithuania. The gross electric power rating of all but two RBMKs is 1000 MWe; the exceptions are the two units at Ignalina in Lithuania which are rated at 1300 MWe gross.

All operating RBMKs were connected to electric power grids during the period 1973 (Leningrad-1) to 1990 (Smolensk-3). They represent distinct generations of reactors having significant differences with respect to their safety design features.

Six plants are considered "first-generation" units (Leningrad-1 and -2, Kursk-1 and -2, and Chernobyl-1 and -2). They were designed and brought on line in the early-to-mid 1970s, before new standards on the design and construction of nuclear power plants (OPB-82) were introduced in the Soviet Union. Units brought on line since the late 1970s and early 1980s are generally grouped as "second-generation" RBMKs (Leningrad-3 and -4; Kursk-3, and -4; Ignalina-1; Chernobyl-3; and Smolensk-1 and -2). Ignalina-2 contains safety features beyond those of other second generation units. These RBMKs were designed and constructed in accordance with the updated standards issued in 1982.

After the Chernobyl accident, Soviet safety standards were revised again (OPB-88). One RBMK (Smolensk-3) has been built to these "third-generation" standards. Additional design changes now are being incorporated in the construction of Kursk-5.

Over the past decade, a considerable amount of work has been carried out by Russian designers and operators to improve the safety of RBMK reactors and to eliminate the causes that led to the Chernobyl accident. As a result, major design and operational modifications have been implemented. However, safety concerns remain, particularly regarding the first-generation units.

This article reviews major efforts for improving the safety of RBMK reactors through a co-operative IAEA programme initiated in 1992. *(See box, page 12.)* Specifically covered are technical findings of safety reviews related to the design and operation of the plants, and the documentation of findings through an Agency database intended to facilitate the technical co-ordination of ongoing national and international efforts for improving RBMK safety.

Scope of the RBMK safety programme

The IAEA's RBMK safety programme aims to consolidate results of various national, bilateral, and multilateral activities and to establish international consensus on required safety improvements and related priorities. It assists both regulatory and operating organizations and provides a basis for technical and financial decisions. A wide range of activities are covered, and since 1992, a number of reviews and assessments have been conducted. Smolensk-3 and Ignalina-2

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RBMK nuclear power plants

Operating units:

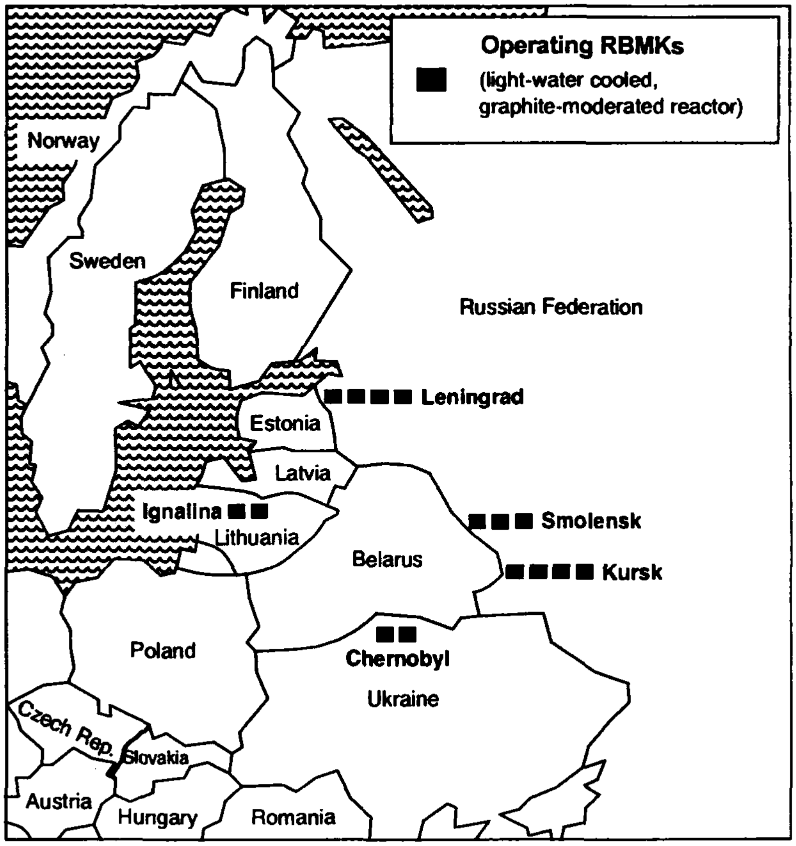
Lithuania. Two 1300-MWe units at Ignalina. *Start of commercial operation:* Ignalina-1 in 1984; Ignalina-2 in 1987

Russian Federation. Eleven 1000-MWe units: four units at Kursk; four units at Leningrad; three units at Smolensk. *Start of commercial operation:* Kursk-1 in 1977; Kursk-2 in 1979; Kursk-3 in 1984; Kursk-4 in 1986. Leningrad-1 in 1974; Leningrad-2 in 1976; Leningrad-3 in 1980; Leningrad-4 in 1981. Smolensk-1 in 1983; Smolensk-2 in 1985; Smolensk-3 in 1990.

Ukraine. Two units at Chernobyl. *Start of commercial operation:* Chernobyl-1 (780-MWe) in 1978; Chernobyl-3 (1000-MWe) in 1982. *Notes:* Chernobyl-2 shut down since 1991; Chernobyl-4 destroyed in April 1986 accident.

Units under construction:

Russian Federation. Kursk-5, a 1000-MWe unit whose construction began in December 1985.



have served as RBMK reference plants during the programme's first phase.

The IAEA conducted a first review of safety improvements proposed for RBMKs in October 1992. In June 1993, a safety assessment of design solutions and proposed safety improvements of Smolensk-3 was organized. It was conducted by an international group of experts and IAEA staff over a period of 2 weeks at the plant site. Smolensk-3 is the most advanced of the operating RBMK plants and its design incorporates safety improvements identified from analyses of the Chernobyl accident and other studies. A similar review was performed for the Ignalina units in October 1994.

Additionally, the Agency's Assessment of Safety Significant Event Teams (ASSET) have reviewed the plant-specific operational experience at all RBMK sites. An Operational Safety Review Team (OSART) mission also was conducted at Ignalina in September 1995.

Experts also have reviewed the design of plant shutdown systems at Smolensk-3. The review — the subject of an IAEA consultants' meeting in Switzerland in December 1993 — was based on IAEA Nuclear Safety Standards (NUSS) documents; national standards (Russia, Canada, and Germany); and regulatory practices of the Organization for Economic Co-operation and Development (OECD). International experts fully supported the intent of Russian designers to improve the RBMK shutdown systems.

Another matter receiving attention has been the analysis of a multiple pressure tube rupture in RBMK-type reactors. At a topical meeting in Moscow in January 1994, participants examined the relevant regulatory approaches adopted in Member States operating channel-type reactors and reviewed the methodology, criteria, and results from safety analyses. They agreed on the urgent need to validate computer codes used for studying loss-of-coolant accident (LOCA) scenarios in RBMKs. In November 1994, at an IAEA consultants' meeting in Japan, a validation matrix for code calculation was established, and in 1995 the IAEA started an international exercise based on experimental results made available by Japan.

Activities of the IAEA's RBMK safety programme are co-ordinated with those of an international consortium on the "Safety of Design Solutions and Operation of Nuclear Power Plants with RBMK Reactors" established under auspices of the European Commission. The two programmes use the same RBMK reference plants.

With the completion in 1994 of the safety reviews of Smolensk-3 and Ignalina-2, these two programmes reached important milestones. To

RBMK Safety Programme

At the start of the 1990s, the IAEA initiated a programme to assist countries of Central and Eastern Europe and the former Soviet Union in evaluating the safety of their first generation WWER-440/230 nuclear power plants. The main objectives were: to identify major design and operational safety issues; to establish international consensus on priorities for safety improvements; and to provide assistance in the review of the completeness and adequacy of safety improvement programmes. The programme's scope was extended in 1992 to include RBMK, WWER-440/213, and WWER-1000 plants in operation and under construction. It is complemented by national and regional technical co-operation projects.

Programme elements include plant-specific safety reviews to assess the adequacy of design and operational practices; reviews under the IAEA's Assessment of Safety Significant Events Team (ASSET) service; reviews of plant design, including seismic safety studies; and topical meetings on generic safety issues. Additionally, follow-up safety missions are conducted to nuclear plants to check the status of IAEA recommendations; assessments are made of safety improvements implemented or proposed; peer reviews of safety studies are performed; assistance is provided to strengthen regulatory authorities; and training workshops are organized. A database also is maintained on technical safety issues identified for each plant and the status of safety improvements.

As an extra-budgetary programme, activities depend on voluntary contributions from IAEA Member States. Steering Committees provide co-ordination and guidance on technical matters and serve as forums for exchange of information with the European Commission (EC) and with other international and financial organizations. The programme takes into account the results of relevant national, bilateral, and multilateral activities, and thus provides a framework in which an international consensus can be reached on the technical basis for upgrading the safety of WWER and RBMK nuclear power plants. The IAEA further provides technical advice within the co-ordination structure established by the Group of 24 OECD countries through the European Commission.

The programme's results, recommendations, and conclusions are only intended to assist national decision-makers who have sole responsibility for the regulation, upgrading, and safe operation of their nuclear power plants. They facilitate but do not replace the need for comprehensive safety assessments in the framework of the national licensing process.

make results available to the international technical community, the IAEA convened a technical meeting in May-June 1995. Results from both the IAEA and EC programmes were presented, thereby reflecting the large amount of work done by the international experts and Russian organizations to review the safety of RBMK nuclear power plants.

Both projects produced a large number of recommendations for enhancing the safety of RBMK plants. Most of them correlate with the measures already included in national programmes for RBMK units which are under way in Russia, Lithuania, and Ukraine.

Based on the initial phase of its programme, the IAEA prepared a consolidated list of design and operational safety issues for RBMKs. For this work, a database of findings and recommendations for RBMKs compiled by the IAEA was used. All findings and recommendations from the various technical meetings, safety reviews of Smolensk and Ignalina, and ASSET reports of the EC's International Consortium were collected in the database and further grouped by topical areas into safety issues. Also included is plant-specific safety information provided by the main design institute for RBMK reactors in Moscow.

The Agency's database has an interface with the databank established by the G-24 Nuclear Safety Co-ordination Group, thus making joint analyses of safety topics and assistance projects easier.

Results from the IAEA programme

The IAEA's programme identifies 58 RBMK safety issues related to seven topical areas. Issues related to six design areas are further ranked according to their perceived impact on plant safety. Safety issues connected to operational areas, particularly those related to the assurance of a high degree of safety culture, are all considered very important.

The ranking of a safety issue does not necessarily imply that all the proposed recommendations have the same urgency for implementation. Therefore, recommendations have to be further considered on a plant-specific basis.

Two broad issues addressing quality assurance (QA) and regulatory matters are not specifically attributed to any particular topical area, but they are recognized as affecting all areas. From the QA standpoint, the main concern relates to ensuring the use of the actual plant status and configuration for various analyses, safety reviews, and safety improvements. Another aspect is ensuring that the relevant design documentation

RBMK Technical Overview

The reactor core of an RBMK is constructed of closely packed graphite blocks stacked into columns and provided with axial openings. Most of the openings contain fuel channels. Some also serve other purposes (e.g. instrumentation and control) and are called "special channels". The graphite stack is contained within a cylindrical steel vessel, 14 meters in diameter, which acts as a support for the graphite stack and as a container for the helium-nitrogen gas mixture.

The total mass of the graphite within the core is 1700 tons. About 6% of the reactor's thermal energy is generated in the graphite stack. The helium-nitrogen mixture improves the heat transfer from the graphite to the channels, protects the graphite from oxidation at its operating temperature of about 650° C and, through gas sampling, forms part of the integrity monitoring system.

There are 1661 fuel channels in the vertical ducts of the graphite columns; these channels are tubes 88 millimeters in diameter made of a zirconium niobium alloy. Each fuel channel contains two fuel assemblies, one above the other, each of them containing 18 fuel rods that are 13.6 millimeters in diameter, enclosed in the zirconium niobium cladding. The total fuel length of the core is about 7 meters.

Number and Category of RBMK Safety Issues

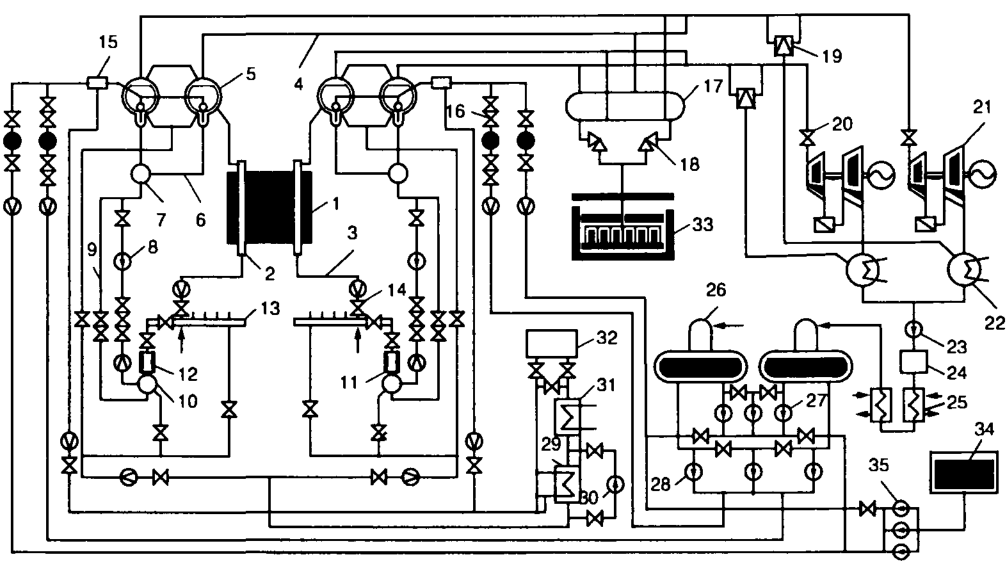
Topical area	Number of safety issues identified	Number of safety issues in category		
		High	Medium	Low
Core design and core monitoring	6	5	1	0
Instrumentation and control	7	2	5	0
Pressure boundary integrity	7	4	2	1
Accident analysis	10	3	7	0
Safety and support systems	10	4	6	0
Fire protection	5	1	3	1
Operational safety	13*	—	—	—
Total	58	19	24	2

* Not ranked, but considered very important and improvements should be implemented in parallel with design modifications.

High: Issues that reflect insufficient defense-in-depth and have a major impact on plant safety. Short-term actions have to be initiated to improve safety as applicable to each specific nuclear power plant until the issue is fully resolved.

Medium: Issues that reflect insufficient defense-in-depth and have a significant impact on plant safety. Short-term actions might be necessary to improve safety as applicable to each nuclear power plant until the issue is fully resolved.

Low: Issues that reflect insufficient defense-in-depth and have a small impact on plant safety. Actions are desirable to improve defense-in-depth, if applicable and effective from a cost-benefit point of view.



1 Reactor
2 Fuel channel
3 Water pipelines
4 Steam pipelines
5 Steam separator
6 Downcomer
7 MCP suction header
8 Main circulation pump
9 MCP header bypass
10 MCP pressure header
11 Mechanical filter
12 Flow limiter
13 Group distribution header
14 Isolation and control valve
15 Mixer
16 Feedwater valve assembly
17 Steam headers
18 Main relief valve (MRV)
19 Steam dump valve
20 Turbine trip valve
21 Turbogenerator
22 Condenser
23 Condensate pump
24 Condensate purification
25 Heater
26 Deaerator
27 Auxiliary feedwater pump
28 Feedwater pump
29 Blowdown regenerator
30 Cooldown pump
31 Blowdown afterheat
32 Bypass purification
33 ALS pool
34 Emergency water tank
35 Emergency feedwater pump

RBMK Basic Design and Safety Improvements

Major safety improvements have been implemented in RBMKs since the Chernobyl accident in April 1986. They address both the direct causes of the accident and other safety shortcomings which have been identified in various analyses.

Reactor Core. Safety modifications directly related to the Chernobyl accident focus on reducing the void reactivity coefficient and improving the control rod design. These modifications have been implemented in all RBMKs. Main measures taken to reduce the void coefficient include:

- loading additional absorbers. The number of additional absorbers varies from 85 to 103 depending on the reactor. Technical specifications require at least 81 additional absorbers.
- increasing the fuel enrichment from 2.0% to 2.4%.
- controlling the operational reactivity margin (ORM). The ORM fully inserted value is controlled between 43 and 48 equivalent control rods.

Emergency Protection System (EPS). Three safety improvements were carried out to improve the EPS efficiency and speed of response. The manual control rods were replaced by rods of an improved design. This includes elimination of the water column at the bottom end of the reactor control and protection system channels, and increasing the neutron absorbing section. The rod drives were also modified, reducing the time required to insert the rods fully into the core from 19 to 12 seconds. These two measures have improved the EPS response efficiency during the first few seconds of rod insertion. As a third measure, a fast-acting EPS was developed and installed in all operating reactors. This system can fully insert 24 control rods in less than 2.5 seconds, or in 7 seconds depending on the emergency signal activated.

Control and Monitoring System. Other measures were taken to improve the control and monitoring system. They include manual reactor trip when the power falls below 700 MW(th); and manual trip if the ORM is less than 30 equivalent control rods.

Pressure Boundary. Two independent loops provide cooling for each half of the reactor core. Each loop contains four main coolant pumps and associated piping. The pressure in the system is 7 MPa.

Emergency Core Cooling System (ECCS). For Smolensk-3, the design basis accident for the ECCS is a double-ended guillotine break of a 900 mm tube and loss of off-site electric power. This corresponds to a break in the main circulation pump pressure headers or suction header. In the event of such an accident, the ECCS makes provision for both fast-acting cooling of the core and long-term decay heat removal. The long-term cooling system comprises six emergency core cooling pumps taking suction from the accident localization system (ALS) for cooling the damaged half of reactor and three pumps taking suction from the tanks for pure condensate for cooling the non-damaged half of the reactor. Both sets of pumps are electrically driven with their power supplies backed up by diesel generators.

Design modifications not related to the causes of the Chernobyl accident are being introduced at first and second generations RBMK plants. Among other steps, these include: increasing the number of emergency feedwater pumps from three to five and the number of ECCS lines from one to two; installing additional ECCS pumps (three for cooling the damaged core side and three for cooling the undamaged side) and the associated three divisions of piping; installing check valves between the distribution group headers and the main coolant pump discharge header; and installing large capacity accumulators.

Accident Localization System. RBMKs are protected by an Accident Localization System (ALS). This pressure suppression system encloses part of the main circulation circuit and consists of leak-tight compartments. All main pipelines, headers, and components carrying cooling water are part of the ALS. The ALS differs considerably in design from one plant to another. The reactor coolant system of first-generation RBMKs is not enclosed in a leak-tight ALS, as is the case at the other RBMKs. Even in these other RBMKs, however, only part of the reactor coolant circuit is confined by an ALS of pressure compartments.

Reactor Cavity Overpressure Protection System (RCOPS). This is an important part of the RBMK's safety system. The cause of overpressurization is postulated to be a failure of pressure tubes inside the reactor cavity. Relief is provided by tubes which connect the reactor cavity to the ALS via a water lock. The design basis accident of RBMK safety analyses is the rupture of one tube. The system has the capacity for two or three channel tube ruptures (for first and second generation units, respectively) which reflects a safety margin over the design basis accident. For first-generation units, the steam discharge system vents the steam/gas mixture from the cavity to a condenser, with the gas subsequently held up and released through the stack.

To improve the capacity of the RCOPS, work is being conducted in stages for all units. At Smolensk-3, the existing system already has the capacity for the simultaneous rupture of up to nine pressure tubes under conservative assumptions of simultaneous ruptures.

is updated as the plant configuration is modified and upgraded. It is therefore of utmost importance that the organizational structure promotes awareness of safety concerns, responds quickly in evaluating these concerns, and implements timely corrective actions if they are warranted.

Exactly how and when identified safety issues are addressed is a matter to be resolved between the operating organization and the regulatory body. The IAEA safety reviews are intended to help by providing international expertise to assist in this process. The reviews draw upon the IAEA's NUSS publications, the Russian regulations, and national practices. Recommendations and conclusions are only intended to provide an additional technical basis for decisions to improve the safety of RBMKs. National authorities have sole responsibility for the regulation and safe operation of their nuclear power plants. Therefore, the results do not replace a comprehensive safety assessment which needs to be performed in the frame of the national licensing process.

Overview of Technical Findings

Core Design and Core Monitoring. The direct causes of the Chernobyl accident were related to the reactor core design. Therefore, safety improvements have been initially focused on identified shortcomings related to core physics.

To date, considerable work has been completed to decrease the core void reactivity coefficient and to increase the efficiency of the shutdown system. However, important issues remain to be resolved. They include the problem of the void reactivity associated with the loss of coolant from channels of the control and protection system (CPS); and the issue of independent and diverse reactor shutdown. International experts thus strongly support the intent of Russian designers to develop and modernize the RBMK CPS to provide a higher safety level.

Another issue of high significance to safety relates to the operational reactivity margin (ORM). The ORM has to be controlled in order to maintain the void reactivity coefficient, the effectiveness of the shutdown system, and the power distribution within defined safety limits. With the present design, it is the responsibility of the operator alone to keep the ORM within the corresponding limits. IAEA programme experts have recommended the automation of shutdown actions when the ORM value falls below the safety limits.

Other aspects of importance concern the process of analyzing RBMK design and safety. Such analyses have been done using calculational tools available at that time. These tools (e.g. computer codes) generally did not have the capability to adequately model spatial interactions between neutronics and thermohydraulics. Consequently, efforts are being directed at the development of three-dimensional methods for analyzing neutron fields, coolant density, and temperature distribution of fuel and graphite. IAEA programme experts have recommended that these methods be used to confirm results of previous safety analyses as well as for further studies.

Instrumentation and Control (I&C). The major concerns related to the segregation between the electronic systems and the level of diversity present in the most important systems and equipment. For example, the flux control system shares many common elements with the shutdown system. Although there is considerable resilience in the system due to the high level of redundancy, the two systems would be vulnerable to common mode failure, and thus control and protection could be lost simultaneously. The Emergency Core Cooling System (ECCS) is initiated by a combination of signals. However, there is no sufficient assurance that the system responds promptly nor that the actuation equipment is designed against single failures.

A safety issue ranked as "medium" is the replacement of the station's main computers. The situation differs from site to site. The equipment in Ignalina, for example, is showing distinct signs of ageing with thermally induced warping of boards and embrittlement of the plastic edge connectors.

A number of other issues related to I&C could be improved by local measures at the plant. These include test and maintenance procedures and the recording and use of failure data.

Pressure Boundary Integrity. Some primary coolant circuit components and piping are outside of the accident localization system. In first-generation RBMKs, a guillotine break in the piping can result in damage to civil structures. Application of the leak-before-break concept would reduce the risk of primary coolant circuit failures. Work is going on to demonstrate the applicability of this concept for RBMK conditions and to implement the method and techniques.

To date, there have been three single-channel ruptures due to the blockage of water flow or an imbalance in the flow-to-power ratio. Recommendations therefore call for analyzing and implementing, as feasible, the reduction of the number of in-line components, whose failure can block water flow.

The IAEA programme's safety reviews indicate that at some plants operation has continued even though the frequency and the number of examinations required by national regulations for the reactor pressure boundary are not performed, or when the results have not been satisfactory. The existing time schedules for implementing modifications, performing additional analysis, and maintaining required record-keeping are sometimes not followed. Criteria for limiting plant operation in these cases are not established.

The required volume of in-service inspection (ISI) is not fulfilled in practice. It was found that in some cases the required number of fuel channels was not inspected. The approach adopted at RBMK plants to repair identified critical defects differs from the predictive approach adopted for ISI elsewhere. Pre-service inspection records and ISI predictive records are not maintained. The existing equipment and procedures are inadequate to give reproducible measurements of small defects below the critical size.

Accident Analysis. The scope of analysis of postulated accidents available in the technical justification of safety (TOB) for RBMKs was determined by national regulations effective when the TOB was issued. Compared to current practices, it was found to be limited and the related information usually does not provide a clear description of assumptions used in the analysis. Computer codes used at the time of RBMK design were of limited modeling capability. The lack of an experimental database on pipe rupture of the primary heat transport system limited the possibility of integral code validation. More modern Russian codes and some Western codes now are being used, but they have not been sufficiently validated for modeling RBMKs.

The review further found a number of areas to be incomplete, including the analysis of Design Basis Accidents (DBA); the adequacy of the codes, database, validation, and documentation for the analysis of loss-of-coolant accidents; and the sensitivity to parameter variations and uncertainties. Additionally, anticipated transients without scram (ATWS) were considered of high safety significance and the analysis of these events needs to be performed.

The completeness of such analysis is of utmost importance to ensure the safe plant design. The analysis should identify possible shortcomings of the existing design and be performed using modern and qualified methods. As design changes are implemented in the plants, the analysis also needs to be updated. An example of this process is the safety analysis report (SAR) work now being performed for the Ignalina plant.

A useful tool in identifying weaknesses and prioritizing improvements is probabilistic safety assessment (PSA). Therefore the performance and peer review of a plant-specific PSA for all RBMKs is recommended.

Safety and Support Systems. In general, it has been found that the high redundancy which exists in several of the front-line safety systems is not present to the same extent in supporting systems, such as the service water and intermediate cooling systems. Moreover, the high level of redundancy in the safety systems cannot always be given full credit due to potential common cause failures.

The reliability of the safety systems is dependent on the system design and alignment and on operational parameters, such as maintenance and testing procedures and emergency operating procedures. Therefore, a strong tie needs to be maintained between this area and the development of emergency operating procedures and testing procedures.

In general, it has been found that the differences between the plants are so important that recommendations in this area have to be evaluated on a plant-specific basis.

Fire Protection. Passive fire protection can address fire safety problems in an effective way. Passive fire protection comprises all the measures that are put in place before the start of operation and are not expected to need any human or mechanical action in case of fire. The basis for prevention of fire damage is the minimization of the amount of burnable material and fire loads. Total elimination of burnable material is preferred, but where this is not possible, the fire load has to be separated into different fire compartments. The basis for compartmentation is the separation of safety significant equipment from each other and from hazardous substances. Compartment boundaries should consist of fixed fire barriers such as walls, floors, ceiling, and mechanical and electrical penetration seals. Also within compartments, important elements may need fire separation. This may take place through distance or local separative elements.

Fire risks were not adequately considered in the design phase of RBMK reactors when passive measures could have easily been implemented. However, much work has been done afterwards. Removal of the largest fire load, the plastic floor coating, has started gradually. Improvement of compartmentation has been carried out by upgrading fire doors and penetration sealings. Within the compartments the main improvement effort has been the covering of cables with a fire resistant protective coating.

These problems have already been tackled to some extent in some RBMK units. In other cases this has been taken care of by a newer design, by national upgrading programmes, or by bilateral/international assistance programmes.

Throughout the plant, all areas with burnable material should be provided with fire detection equipment connected to a proper alarm system. The existing systems need both extension and quality upgrading. Some plants have started these measures as a part of their own upgrading programme, and some in connection with bilaterally or internationally financed programmes.

Manual fire suppression capability is generally very strong at nuclear power plants in the former Soviet Union. This applies to the number and the training of fire brigade personnel. Deficiencies, however, exist in the personal protective equipment, communication equipment, and fire fighting equipment, such as fire extinguishers, hoses, and nozzles.

Automatic fire suppression is mainly realized through fixed water sprinkler and deluge extinguishing systems. Local carbon dioxide or foam extinguishing systems also exist. The reliability and coverage of the existing systems need evaluation. Automatic fixed water extinguishing systems should be added to some compartments which so far have not been fully protected.

The reliable supply of water assures proper availability and operation of both manual and automatic fire suppression capability. However, differences between sites and the different generations of RBMKs are extensive and measures of different magnitude are needed.

Operational Safety. Past experience in the operation of nuclear power plants confirms the important role of plant personnel in assuring nuclear safety. Considerable attention has been given to the study of human factors in plant operation. Overall, it has been found that the operational safety of RBMKs can be upgraded. Identified safety issues include those relating to the training of operators; operating and emergency management procedures; and surveillance, maintenance, and control of plant modifications. Recommendations have been made in these areas and should be implemented in parallel with proposed design and safety improvements.

A stronger technical basis

On the basis of national and multilateral safety reviews, the main safety concerns of the more modern RBMK nuclear power plants have been identified and the required safety improvements have been agreed upon.

Despite the work carried out to date, safety concerns remain, particularly those related to the first-generation units. Future IAEA activities will focus on assisting in the review of first-generation units and on streamlining efforts to resolve generic safety issues.

Up-to-date information on the plant-specific status of operating RBMKs is essential for an effective exchange of technical information and for the co-ordination of national and international efforts to improve nuclear safety. The database established by the IAEA is an effective tool to facilitate this co-ordination. The work ahead will enable the compilation of more plant-specific information in the interests of tracking the status of safety improvements and identifying areas where more efforts need to be taken. ❐

Participants in the safety review at the Smolensk plant under the IAEA's extra-budgetary RBMK safety programme.

Chernobyl & the marine environment: The radiological impact in context

Scientists at the IAEA's Marine Environment Laboratory in Monaco have played an integral role in post-Chernobyl studies

by
Pavel Povinec, Scott Fowler, and Murdoch Baxter

The Chernobyl nuclear accident in April 1986 had a significant impact on both the terrestrial and marine environments. The total activity of the nuclear debris released was so high ($1\text{-}2.10^{18}$ becquerel) that the radioactive fallout distributed widely after the accident actually dominated anthropogenic environmental levels in various parts of the world.

Concentrations of anthropogenic radionuclides generally vary from region to region, according to the location and magnitude of the different sources of contamination. The main global contribution to marine radioactivity, as in the terrestrial environment, is still from fallout from nuclear tests in the atmosphere, particularly during the 1950s and 1960s.

However, in some regions, like the Irish and North Seas, the concentrations of anthropogenic radionuclides (e.g. caesium-137 and plutonium-239) in the marine environment have been significantly influenced by discharges (e.g. from European reprocessing plants). On the other hand, the Baltic and Black Seas have been the seas most affected by the Chernobyl accident. In all these latter regions the spatial and temporal trends in the concentrations of anthropogenic radionuclides have been quite dynamic. They are a result of changing source terms and marine processes, including horizontal and vertical transport in seawater, marine sedimentation, resuspension from sediment and biological uptake, and food-chain transfer.

IAEA-MEL tracer studies

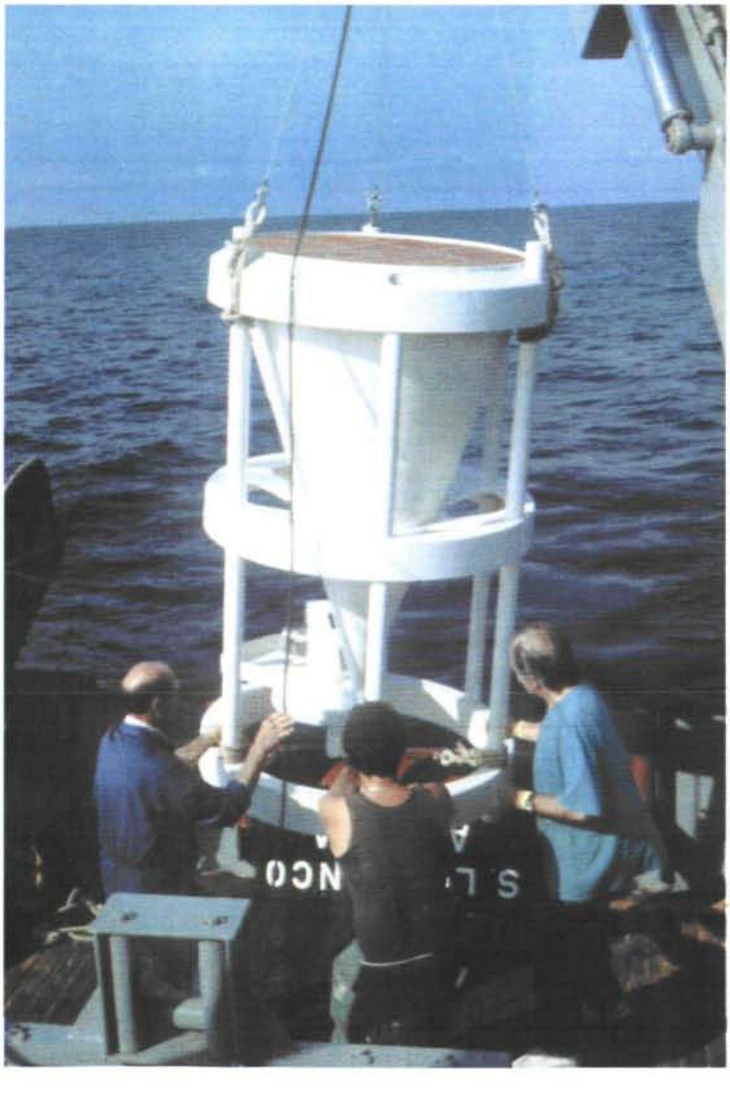
The Chernobyl accident, perhaps surprisingly, was of considerable interest to oceanographers around the world. The accidental release of substantial amounts of radioactivity to the atmosphere essentially initiated a worldwide transient tracer experiment on a scale that would never have been planned deliberately. Shortly after the accident, fission and activation products released by the fire entered marine waters throughout Europe. They became involved in many of the elemental cycles that oceanographers have for decades been trying to characterize using a wide variety of conventional techniques. Suddenly, immediately after the Chernobyl accident, a suite of radioactive tracers became available as a pulse to trace, rather like a coloured dye, the movement of elements through the oceans. IAEA-MEL scientists took part in this exciting and serendipitous experiment through temporal radionuclide monitoring of both the coastal and open ocean ecosystems.

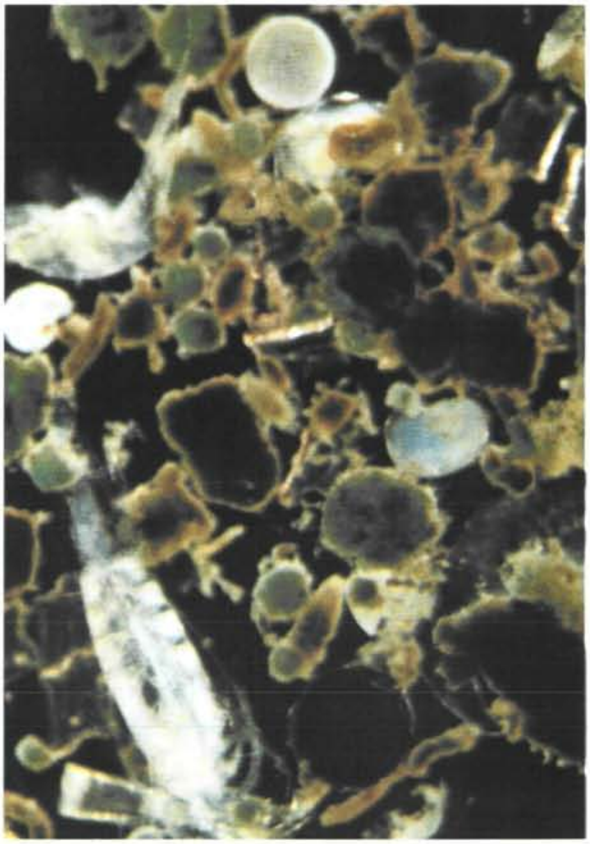
For open sea work, one of the most important innovations in marine monitoring over the past 15 years has been the development of sediment traps to directly measure fluxes of materials associated with sinking particles. Moored sediment traps can be left unattended at any depth in the ocean to collect discrete, time-series samples at pre-determined intervals.

As part of a joint French-IAEA study of open Mediterranean particle flux, in mid-April 1986, IAEA-MEL scientists had, by a happy coincidence of timing, moored their automated time-series sediment trap at a depth of 200 meters in the Ligurian Sea between Monaco and the island of Corsica. In order to study timescale changes in particle flux, each of the six trap collection cups was set to sample sinking particles for consecutive periods of 6.25 days. Following the accident on 26 April, atmospheric measurements made at Monaco by IAEA-MEL indicated that most of the peak Chernobyl fallout entered the Ligurian Sea essentially as a single pulse during the period 4-5 May.

The sediment trap was retrieved on 22 May and the particulate material, along with other

Mr Baxter is the Director, Mr. Fowler, Head of the Radioecology Section; and Mr Povinec, Head of the Radiometrics Section of the IAEA's Marine Environment Laboratory in Monaco.





Top: **As part of an IAEA-MEL training course in Istanbul in November 1994, scientists collect sediment samples in the Marmara Sea using the University of Istanbul's ship.** *Left:* **A team of IAEA-MEL scientists deploy a sediment trap such as the ones used during their post-Chernobyl marine studies.** *Above:* **Typical particles collected in sediment traps include oval, rectangular, and cylindrical fecal pellets produced by zooplankton that are actively feeding on micro-organisms.** ***(Credits: IAEA-MEL).***

marine samples, was analyzed for radioactivity by gamma spectrometry. The radioanalyses showed that the primary pulse of particulate radionuclides arrived at 200 meters depth between 8 and 15 May, that is only about seven days after peak radioactivity was delivered to the sea surface. The time lag implied an average sinking speed of the radioactive particles of approximately 30 meters per day. This pulse of radioactivity sinking through 200 meters was particularly evident for the particle-reactive fission products (e.g. zirconium, niobium, and cerium radionuclides) which were either not detectable or present in very low amounts in the last sediment trap sample collected after 15 May.

The rapid descent of these radionuclides on a timescale of a few days indicated that they were not sinking as fallout particles according to Stokesian settling models. Rather, they were incorporated into large aggregates which are known to sink at speeds of tens to hundreds of meters per day.

From earlier laboratory research at IAEA-MEL, it was suspected at the time of the accident that biological activity in surface waters might be responsible for absorbing radionuclides like a sponge and removing them to depth. Primary production of minute plant-like phytoplankton cells creates solid surfaces onto which contaminants like radionuclides are adsorbed. The zooplankton which feed on these radioactive cells subsequently defecate large aggregates (fecal pellets) which can further scavenge radioactivity as they sink.

Therefore, to test this hypothesis, on 6 May 1986 live zooplankton were netted from the waters over the sediment trap and allowed to defecate in special aquaria on board ship. When analyzed, these freshly produced fecal pellets were found to contain radionuclides with similar concentrations and relative distributions as were present in the sinking particles trapped at 200 meters. Microscopic examination of the trap samples confirmed that they were rich (70% by weight) in the same type of fecal pellets as the netted zooplankton had produced. Thus, this accidental "field experiment" was actually the first direct and convincing demonstration of the biological processes by which ocean waters are cleansed of contaminants like radionuclides.

Following the Chernobyl accident, the different radionuclides which entered the surrounding seas were removed to different degrees depending upon their chemical reactivities. For example, in the case of the particle-reactive radionuclides, cerium-141, cerium-144, and plutonium-239+240, from 50% to 75% of the total radionuclide inventories deposited in this region of the Mediterranean had transited through 200 meter depth by one month after the accident when the sediment trap stopped sampling. In sharp contrast, only 0.2% of the corresponding caesium-137 deposition had passed through 200 meters by that time, an observation which is consistent with the generally non-reactive behaviour of this long-lived nuclide in seawater. For this reason, Chernobyl-derived caesium-137 has proved to be very useful as a water mass movement tracer in the Mediterranean and other seas for several years after the accident.

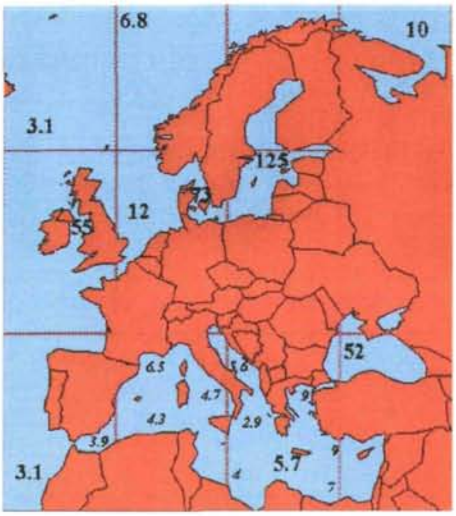
IAEA-MEL was not the only group of marine scientists deploying sediment traps in European waters following the Chernobyl accident; time-series traps were collecting particles at nearly the same time in the North Sea, the Black Sea, and Lake Zurich. Where comparisons could be made, concentrations of Chernobyl-derived radionuclides in the different sinking particles were surprisingly similar, and in most cases biological activity in the upper water column was considered to be the driving force in transporting the radioactivity downward. However, large differences in radionuclide flux were evident due to variations in particle mass flux which is normally site and depth specific. The extreme case was observed in Lake Zurich where roughly 20% of the fallout was removed from the water column in two months due to the sinking of a massive bloom of calcareous algae.

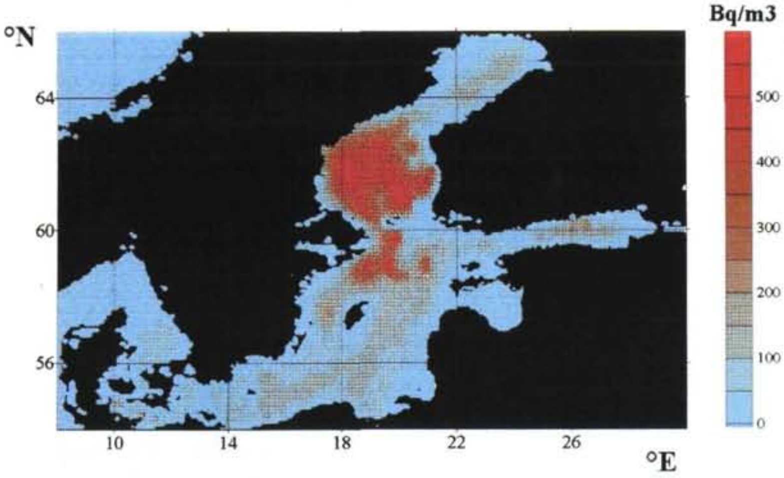
Viewed collectively, the temporal flux data for the Chernobyl radionuclides collected throughout Europe after the accident have proven extremely important for refining general models of contaminant removal and transport in aquatic systems.

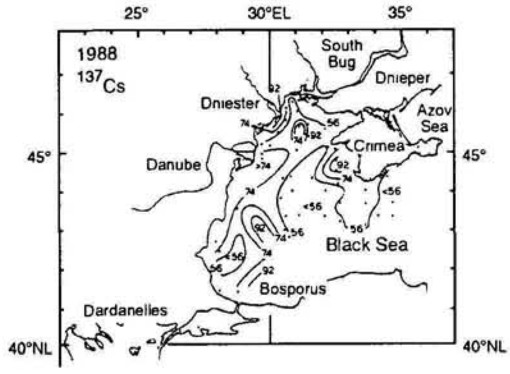
Environmental & radiological aspects

Of more than 20 radionuclides which were released in significant quantities during the Chernobyl accident, only a few have been studied extensively in the marine environment. Among the most important have been strontium-90, caesium-134, caesium-137, and plutonium-239+240. Other radionuclides, such as iodine-131, have half-lives that are too short to be harmful or relevant to understanding marine processes, or had very low concentrations (for example, iodine-129).

As mentioned previously, considerable differences in marine behaviour were observed. Strontium-90 and caesium-137 are typical representatives of elements which are soluble in seawater and can be used for studies of water dynamics. Their particle reactivity is very low in comparison to, for example, plutonium isotopes, which lie at the other extreme, in a group of







Above left: **The average caesium-137 activity of surface seawater (Bq m^{-3}) estimated for the reference year 1990. The Mediterranean regional sea values were extracted from the Commission of the European Community's MARINA-MED report.**
Above right: **Caesium-137 contours in the surface seawater of the Baltic Sea for the period 1986-88 as extracted from the IAEA-MEL Global Marine Radioactivity Database. The data were mostly supplied by the Bundesamt für Seeschiffahrt und Hydrographie, Hamburg, Germany.**
Right: **Caesium-137 activity isolines (Bq m^{-3}) in surface waters of the western Black Sea as extracted from the measurements in 1988. Adapted from G. G. Polikarpov** ***et al., Journal of Environmental Radioactivty*** **(Vol.13,1 (1991)).**

elements having low solubility and high particle reactivity. Plutonium isotopes do not travel long distances from the source because they are deposited into sediment, which therefore contains their main inventory in the ocean.

As the plutonium input to the oceans following the Chernobyl accident was small and localized, this article will concentrate on discussing the impact of Chernobyl radiocaesium on the marine environment. The caesium isotopes were both the most widespread and most abundant of the ones released.

The behaviour of radiocaesium in the oceans has been studied over a long period with reference to its fallout from nuclear bomb tests and in discharges from nuclear reprocessing plants. In particular, discharges from Sellafield in the United Kingdom have been extensively used to study water and sediment dynamics in the Irish, North, and Norwegian Seas. The radiocaesium from weapons test fallout was exclusively caesium-137. Caesium-134 has, however, been present in Sellafield discharges as well as in Chernobyl debris. The ratios of caesium-134 to caesium-137 have been different, however. Caesium from Chernobyl was thus readily distinguishable from other sources by having a different caesium-134/caesium-137 activity ratio of about 1:2.

Radiologically, the sea most affected by the Chernobyl accident was the Baltic, since the first radioactive clouds from Chernobyl travelled to the north and caused high deposition over the Scandinavian region. Atmospheric deposition played a dominant role in determining the radioactivity of this sea. The mean caesium-137 concentration in surface waters estimated for the reference year 1990 was highest in the Baltic Sea. *(See maps.)* Because of the closed nature of this sea and its small exchange of water with the North Sea, the levels of caesium-137 of this sea have remained the highest in Europe.

Caesium-137 contours shown on the map of the Baltic Sea for the period 1986-88 illustrate the enhancement of caesium-137 concentrations in seawater, with clear evidence of the effect of run-off from land, particularly from Sweden. The measured range in 1986 was from a few becquerel (Bq) to 2400 Bq per cubic meter, i.e. two to three orders of magnitude higher than in other European seas.

The next most perturbed sea following the Chernobyl accident was the Black Sea, where the mean caesium-137 concentration in seawater in

1990 was 52 Bq per cubic meter, comparable to that in the Irish Sea. The highest deposited activity was observed in 1986 in its northernmost area, about 500 Bq per cubic meter, i.e. 30 times higher than the pre-accident values. Strontium-90 activity measured in 1988 in surface waters of the western Black Sea was mostly between 10 and 50 Bq per cubic meter. Generally, a similar distribution was observed in 1988 for caesium-137 as well, but the levels were higher for this radionuclide by a factor of two. Strontium-90 and caesium-137 surface concentrations in Aegean Sea waters were much lower, between 5 and 11 Bq per cubic meter. The distribution patterns of strontium-90 and caesium-137 observed in the surface waters of the Black Sea can be explained in terms of two main source functions — namely by a short-term atmospheric deposition which dominated immediately after the accident, and then by a long-term transfer from the Kiev Reservoir and the catchment area of the Dnieper, Dniester, and Danube rivers.

For the Mediterranean Sea, the main Chernobyl contribution then arrived by exchange of waters with the Black Sea, which has essentially acted as a radioactive source. Atmospheric deposition and river inputs were estimated to have played minor roles. The mean caesium-137 concentration in surface water estimated for 1990 was 5.7 Bq per cubic meter. The caesium-137 levels in regional seas as estimated by the Commission of the European Community's MARINA-MED project ranged from 2.9 to 9 Bq per cubic meter, clearly showing a west-east trend towards the highest values in the Aegean Sea.

Technical assistance and training

The IAEA has been active in assisting Member States both to monitor and understand the effects of the Chernobyl accident on their marine systems. Firstly, in the Black Sea region where Chernobyl radioactivity is among the foremost public concerns in relation to health, the IAEA has initiated a major programme of technical co-operation. Activities are directed at strengthening the capabilities of the regional Member States to measure and monitor marine radioactivity, especially alpha-emitters, and involve careful evaluation and selection of equipment and training approaches.

In November 1994, a 2-week regional training course on marine radioactivity monitoring was held in Istanbul. In addition, a complementary Co-ordinated Research Programme (CRP) on isotopic tracers in the Black Sea has been carried out. It is being done with a view to using the Chernobyl pulse of radionuclides and related nuclear techniques to understand water movement and element cycling in the heavily polluted marine system.

In the Baltic Sea, the Helsinki Commission MORS programme (Monitoring of Radioactive Substances) has received significant support from IAEA-MEL in terms of organization of specially designed analytical quality assurance exercises for marine radioactivity assay. This support will be further increased by the organization, in Finland, of an IAEA training course on marine radioactivity studies in September 1996. Again, the work will feature particular reference to the Chernobyl impact and to the needs of the new Baltic States (Estonia, Latvia, and Lithuania) which have joined the IAEA.

Overview of marine radioactivity

An overview of marine radioactivity perspectives has been provided by the IAEA's recently completed CRP, "Sources of Radioactivity in the Marine Environment and their Relative Contributions to Overall Dose Assessment from Marine Radioactivity (MARDOS)". This study provided new up-to-date estimates of doses to the public from anthropogenic caesium-137 (originating from global fallout, the Chernobyl accident, and authorized discharges) and from natural polonium-210 through consumption of marine food.

It included a study of fishing areas as defined by the United Nations Food and Agriculture Organization (FAO). Analysis of fishing area No.37 (the Mediterranean and Black Seas) has shown that the collective effective dose commitment for caesium-137 in marine food (fish and shellfish) in 1990 was 6 man sievert (Sv) — much smaller than the 700 man Sv derived from polonium-210 ingestion. The highest doses (86 man Sv) in world oceans due to caesium-137 were found in the North Atlantic area (FAO fishing area No. 27, which also includes the Irish, North, Baltic, Norwegian, and Barents Seas). However, they are still negligible in comparison with 2900 man Sv derived from polonium-210 ingestion.

Generally, it can be concluded that the Chernobyl accident has had a measurable impact on the marine environment. Radionuclide levels (mainly caesium-137) were two to three orders of magnitude higher than the pre-Chernobyl levels. However, the doses to the public from ingestion of caesium-137 in marine food have been estimated to be at least an order of magnitude lower than those due to natural polonium-210. ❐

Nuclear and radiation safety: Guidance for emergency response

Criteria have been established at the international level to guide decisions about protective actions after a nuclear or radiological emergency

by
Malcolm Crick

Accidents involving radioactive materials in recent years have had consequences for the health of the general public. These have ranged from the major accident at Chernobyl in 1986 to accidental dispersion of medical and industrial radioactive sources.

Responses to these accidents differed between countries. It later became apparent that some protective actions were taken that, in the most extreme cases, may have worsened, rather than improved, the well-being of the populations involved and their environmental surroundings. In other cases, the actions led to large but unproductive expenditures of national resources. Further, where the accident involved exposure of populations across national boundaries, many instances occurred of contradictory national responses either side of the national borders.

During the past decade considerable progress has been made in developing internationally recognized principles for decisions on protective measures following accidents involving radioactive materials, and in providing quantitative guidance for applying these principles. Efforts have involved the IAEA, the International Commission on Radiological Protection (ICRP), World Health Organization (WHO), Food and Agriculture Organization (FAO), Commission of the European Communities (CEC), and Nuclear Energy Agency of the Organization for Economic Co-operation and Development (OECD/NEA).

This article summarizes guidance on the radiation protection criteria that have been established with regard to responding to nuclear accidents or radiological emergencies, and the principles for establishing intervention levels. The guidance was developed to assist those at national and regional bodies and at nuclear facilities having responsibility for emergency response planning.

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Establishing international consensus

In 1985, the Agency published *Safety Series No. 72*, which set out guidance on the principles for establishing intervention levels for the protection of the public in the event of a nuclear accident or radiological emergency. That guidance was aimed at assisting national and regional authorities having responsibility for emergency response planning to specify levels of projected dose at which it may be necessary to introduce relevant protective measures. It recognized a need for practical quantities that could be readily compared with the results of measurements made in environmental materials and in foodstuffs, so-called Derived Intervention Levels (DILs). Shortly after the accident at the Chernobyl nuclear power plant in 1986, the Agency published *Safety Series No. 81*, which addressed the principles, procedures, and data needed to establish these DILS. Guidance was also given on the extent to which the supportive numerical data and the illustrative DILs might have more generic application.

Additionally over the past decade, new recommendations for radiation protection have been issued by the ICRP; the FAO/WHO Codex Alimentarius Commission published Guideline Levels of Radionuclides in Food Moving in International Trade; WHO issued recommendations on Derived Intervention Levels for Protecting the Public; and the International Chernobyl Project made a number of important recommendations.

In 1991, the IAEA revised its *Safety Series No. 72* to clarify the guidance with respect to intervention, and provided illustrative examples of how intervention levels are established in emergency plans. It stopped short of providing numerical intervention levels that might have some generic application.

The emergency response to the Chernobyl accident underscored the need for a simple set of consistent intervention levels at the international level. Such a set of values was considered desirable to increase public confidence in authorities charged with dealing with the aftermath of an accident. Additionally, since many countries do not have nuclear facilities and hence detailed emergency plans themselves, a simple internationally agreed set can assist them in the event of transboundary releases.

In the process of establishing international consensus on the values of these generic intervention levels, the IAEA convened a number of technical meetings. The work led to the preparation, in 1993, of *Safety Series No. 109, Intervention Criteria in a Nuclear or Radiation Emergency.* This Safety Guide, published in 1994, represents the international consensus reached on principles for intervention and numerical values for generic intervention levels. These principles and values subsequently became the basis of intervention guidance in the *Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources*, which have been issued jointly by the IAEA, FAO, ILO, NEA, PAHO, and WHO.

Summary of guidance

Prompt and Delayed Radiation Effects on Health. For most prompt (or deterministic) effects on health, the severity is related to the level of dose to the individual and there is a practical threshold radiation dose below which effects are not clinically observable. The most severe consequence is death, which may occur in sensitive individuals, due to bone marrow failure, at doses above one gray (Gy) delivered promptly to the whole body. Serious prompt effects may also occur in other organs. Most of the threshold doses for these are above that for bone marrow and will be avoided if the dose to the whole body is below one Gy. However, some individual organs, such as the thyroid and the lung, may receive high doses due to breathing or swallowing certain radionuclides and must be considered separately.

Delayed (or stochastic) effects include a wide range of cancers and hereditary effects, for which the probability of occurrence (not the severity) increases with dose. They usually appear many years after exposure, and, although they do not occur in every exposed individual, there is no threshold for their induction. Because of the assumed linear (proportional) relationship between dose and the probability of these effects, it is possible to estimate the number expected to occur in a large exposed population even if the chance of an effect is very small for most individuals. Since other causes (mostly unidentified) can give rise to the same effects, it will be usually impossible to identify those caused by radiation.

Typically, even a severe accident will cause high doses to relatively few and small doses to many people. Most cancers and hereditary effects will occur in large populations that receive small doses. These usually cannot all be avoided and the objective of intervention is to reduce their number as much as is reasonably possible.

Exposure Routes and Dose Projections. Although accidental releases may occur to air, water, or land, those most likely to require urgent protective action are major releases to air. Following such a release people may be exposed to radiation from the airborne radioactive cloud and through inhalation of radioactive dust from the cloud. As the cloud disperses, particles will slowly settle on the earth's surface or be deposited rapidly by rainfall. People then may be exposed to radiation from these deposits, from inhaling resuspended dust, or from contaminated food or water.

During an accident, potential doses to the population will usually be estimated by well-qualified professionals. However, early on, there are many uncertainties (e.g., in the amount and rate at which radioactive material is being released and in the meteorological situation). Because of this and the need to use simple mathematical models to obtain results soon enough to be useful, there will be large uncertainties in early dose estimates.

Decision-makers must be aware of this situation and ensure that their expert advisors provide an expression of uncertainties in early estimates of projected doses. They should not rely on "most likely" estimates alone (which could lead to wrong conclusions with severe repercussions for the population) and must consider the uncertainties in arriving at a suitable decision on urgent protective action. Later, as the situation becomes clearer, it will be possible to modify and initiate protective actions with a much firmer grasp of projected doses.

Normal and Emergency Situations. Under normal conditions, doses from man-made sources (e.g., from nuclear power or the practice of medicine) are kept within specified levels. These are much lower than would prompt a need for protective action; typically they are comparable to local variations in natural background radiation. They are achieved through the use of controls on the radiation source and do not require direct constraints on people.

In the event of an accident, radioactive material released into the environment is no longer under control; doses can only be reduced through protective actions — such as evacuation, sheltering, relocation, resettlement, prophylatic use of iodine, and restrictions on food and water — all of which impose constraints on people's activities. These actions may also incur additional risks. Therefore, in choosing the level at which a protective action should be initiated, it is necessary to consider the effects of constraints on people's activities and any additional risks from the action itself.

For the above reasons, the levels of dose for intervention following an accident and the levels for control of doses under normal conditions will be different and it is important to avoid confusion between the roles of these two different kinds of levels.

Protective Actions. There are limited major options available to protect the public after an accident. The most important are the following:

For early, or urgent, response: 1) sheltering, through advising people to remain indoors and close their doors and windows, usually for less than a day; 2) evacuation, the urgent removal of people from a specified area for periods on the order of days; and 3) prophylactic administration of iodine, if high intakes of radioactive iodine have occurred or are expected to occur.

For later phases of the response: 1) temporary relocation of people to a new habitat, usually for no longer than one to two years; 2) permanent resettlement of people in new or existing settlements for the foreseeable future; and 3) control of food and water contaminated in excess of specified levels.

Principles and levels of intervention

Three principles have been agreed upon by the international community as a general basis for intervention. They may be paraphrased as follows: 1) Intervention to avoid serious prompt health effects should be carried out as a first priority. 2) Protective actions to avoid delayed health effects should be initiated when they will produce more good than harm in the affected population; and 3) These actions should be introduced and withdrawn at levels that produce a maximum net benefit to the population.

The first principle is critical for response to an accident producing any high doses. It means that any immediate threat to individuals should be countered through evacuation (or, rarely, sheltering) (and, when appropriate, iodine prophylaxis) as a first priority, and carried out to the maximum extent of immediately available resources. There may be rare cases when evacuation to satisfy this first principle is not appropriate because it could cause greater harm (e.g. moving people on life support systems, or in the face of a competing disaster).

Intervention levels for minimizing delayed health effects are based on the second and third principles. In applying these principles, the terms "good," "harm," and "benefit" include — in addition to health and safety and the tangible costs of protective actions — unquantifiable factors such as reassurance, stress, and attention to societal values. These are not within the primary professional competence of the radiation protection expert. They are more appropriately the responsibility of the decision-maker. He or she may choose to consider these factors, in addition to those addressed by this radiation protection advice, in arriving at decisions that will produce the maximum benefit in the affected population.

Furthermore, the second and third principles address only the risk of delayed effects in the population as a whole. This means that they do not explicitly limit individual risks. A significantly higher than normal risk of delayed effects to even a few individuals may be an important factor in national decision-making. For this reason authorities may choose an action level to avoid unacceptably high individual risks. Whether intervention at such a level is always possible will depend on the accident's severity and nature and the resources at the disposal of the country. Such action levels were not considered in deriving the generic intervention levels in *Safety Series No. 109* and may lead to lower values for intervention, particularly in the case of protective actions for later phases of a response.

Protective Actions for Early, or Urgent, Response. These actions must be applied promptly in order to be effective. Delays may lead to population doses that could have been avoided and in the worst cases could lead to prompt health effects. Rapid decisions are difficult because there is usually very limited early information about an accident and large uncertainty about its consequences. For this reason pre-planning should be carried out wherever possible so that decisions can be made rapidly based on facility conditions and pre-arranged patterns for response, rather than just on measurements carried out and actions hastily organized during the early course of an accident. In the case of fixed facilities with well-understood characteristics, response plans should prescribe action to implement urgent protective actions on the basis of facility conditions, rather than rely on confirmation of an actual release through measurements at the facility or offsite, whenever it is reasonably feasible to do so.

Sheltering means staying in buildings to reduce exposure to airborne contamination and surface deposits, and closing doors and windows and turning off ventilation systems to reduce inhalation of radioactive material from outside

Generic intervention levels in emergency response situations

Urgent protective actions

Action	Avertable dose (Generic intervention level)
Sheltering	10 mSv for a period of no more than 2 days
Iodine prophylaxis	100 mGy (committed absorbed dose to the thyroid)
Evacuation	50 mSv for a period of no more than 1 week

Generic action levels for foodstuffs

(From the CODEX Alimentarius Commission guideline levels for radionuclides in food moving in international trade following accidental contamination)

<table>
<tr><th>Radionuclides</th><th>Foods destined for general consumption (kBq/kg)</th><th>Milk, infant foods, and drinking water (kBq/kg)</th></tr>
<tr><td>Caesium-134, Caesium-137, Ruthenium-103, Ruthenium-106, Strontium-89</td><td rowspan="2">1</td><td>1</td></tr>
<tr><td>Iodine-131</td><td rowspan="2">0.1</td></tr>
<tr><td>Strontium-90</td><td>0.1</td></tr>
<tr><td>Americium-241, Plutonium-238, Plutonium-239</td><td>0.01</td><td>0.001</td></tr>
</table>

Long-term actions

Action	Avertable dose (generic intervention level)
Initiating temporary relocation	30 mSv in a month
Terminating temporary relocation	10 mSv in a month
Considering permanent resettlement	1 Sv in a lifetime

air. Sheltering can also facilitate staging for evacuation and the prophylactic use of iodine. Because of the small penalties, sheltering may be justified at low dose levels. However, its effectiveness decreases rapidly with time for most structures (typically reducing doses to airborne particulates by a factor of two or three in a few hours) and is low for lightweight structures or those with high air exchange rates. Further, there is a limit to the time that populations can remain indoors without undesirable complications.

The generic intervention level for sheltering is 10 mSv. This value was selected based on the maximum anticipated period of sheltering (2 days). Sheltering may be advised at lower levels for shorter periods or to facilitate other protective actions.

Sheltering can be effective if the exposure is of short duration and buildings are of dense structure and well sealed, as in some northern countries. In many warm countries, however, most houses are made of light materials, and people cannot stay indoors in sealed houses for long periods. These factors must be considered when choosing between protective action through sheltering versus evacuation.

Evacuation is the urgent moving of people from their normal housing for a limited period of time. Its use should be based on the dose that can be avoided by evacuation and would not be avoided by sheltering. The generic intervention level for evacuation is 50 mSv. This value has been selected based on the maximum anticipated period of evacuation (7 days). Evacuation may be initiated at lower levels for shorter periods or when it can be carried out easily, e.g. for small groups of people. Under exceptional circumstances (such as hazardous weather, or the presence of a competing disaster) or where evacuation would be unusually difficult (for very large populations or in the absence of adequate transportation) initiation of prompt evacuation may be deferred to a higher intervention level.

In cases before an actual release has started, and where projected doses exceeding this level have a relatively high probability of occurrence, preventive evacuation normally will be advisable. Evacuation as a protective action is commonly used when people are threatened by other man-made hazards (e.g., fire or chemical spills) or by forces of nature (e.g., hurricanes, tornados, earthquakes, or floods). In most cases people return in a short period, typically one to two days, if their homes do not require prolonged clean-up. Because of the short time involved, primitive accommodation in schools or other public buildings is typical.

Prophylactic use of iodine is the administration of stable (non-radioactive) iodine in order to block the uptake of radioiodine by the thyroid. It must be carried out promptly to be effective (ideally several hours before and no later than a few hours following exposure). For this reason this protective measure is most commonly practical only when emergency planning has included predistribution of stable iodine to the population at risk. It will usually be coupled with evacuation or sheltering. The generic intervention level for prophylactic use of iodine is 100 mGy. This level applies to the dose to the thyroid that would be received from intake of radioiodine. Since there may be complications depending on local diet and other factors, public health authorities should be involved in implementing this measure.

Protective Actions for Later Phases of a Response. Sheltering and evacuation are short-term protective measures. If measurements confirm that doses warrant further action, temporary relocation or permanent resettlement, and control of food and water may be necessary.

For early protective actions, the greatest benefit is likely to accrue if action is taken with minimal delay, based on rough predictions of how the accident will develop. For long-term protective actions, there will usually be a rather small radiological health penalty for delaying to obtain accurate measurements for projecting doses. Moreover, the social and economic penalties for imprudent decisions can be high, owing to the long period protective actions may be in effect. It is important that a decision to implement these protective actions is carried out in as informed a manner as possible, using best estimates for the consequences of different options.

Temporary relocation means the organized removal of people for an extended but limited period of time (e.g., several months) to avoid doses from radioactive material deposited on the ground, including resuspended materials, and in some cases from local food or water. People typically would be housed in temporary accommodation of a reasonable minimum standard of comfort and privacy. The generic intervention levels for initiating and terminating temporary relocation are 30 mSv in a month and 10 mSv in a month, respectively; i.e., people should be temporarily relocated if the dose avertable over the next month is expected to be greater than 30 mSv. They may return when the avertable dose falls below 10 mSv in a month. However, if the dose accumulated in a month is not expected to fall below this level within a period of a year or two, the population should be permanently resettled. Two levels are specified because there are relatively high penalties for initiating relocation compared to maintaining it. It is also necessary to specify the period of time it is reasonable to live in temporary housing.

Permanent resettlement means complete removal of people from the area with no expectation of return for at least several years. People typically would be resettled in accommodations comparable to those vacated. This may involve construction of new housing and infrastructure. The generic intervention levels for permanent resettlement are 1 Sv in a lifetime or a dose exceeding 10 mSv per month that persists beyond one or two years (i.e., that does not permit return from temporary relocation within one or two years). It should be recognized that projected doses below the intervention levels for evacuation or for terminating temporary relocation could also, over a lifetime, become high enough (i..e., exceed 1 Sv) to warrant permanent resettlement.

Control of food and water may have to be considered under three different circumstances: where alternative supplies are available; where alternative supplies are scarce; and for distribution in international trade. Generic action levels have been established for use by national authorities when alternative supplies of food are available. *(See table.)* The values depend upon the type of foodstuff and the type of contaminating radionuclide. The radionuclides in question are those most likely to be of concern in foods following an accident.

In situations where extensive restrictions on food supplies could result in nutritional deficiencies or, in the extreme, starvation, case-by-case evaluations will be required. In most such situations relocation will be indicated, and alternative food made available. However, when this is not possible, the radiation hazard must be considered realistically in comparison to competing health hazards, and higher action levels should invariably be adopted.

Following any event that may contaminate foodstuffs, a variety of countermeasures may be instituted at various stages in production and marketing. These should be implemented to ensure that, to the maximum extent practicable, foodstuffs are maintained below the action levels. The generic action levels for foodstuffs will also satisfy the requirements for distribution of foodstuffs in international trade for consumption in countries unaffected by an accident. ❐

Electricity, health & the environment: Selecting sustainable options

At an international symposium on comparative energy assessment, experts reviewed key issues facing decision-makers

by
Leonard Bennett and
Malik Derrough

Demand for energy, and notably electrical energy, will grow significantly, especially in developing countries, as the world's population increases. Which energy options are selected will significantly affect the world's achievement of sustainable social, economic, and environmental development.

In many countries, energy planners and decision-makers are facing difficult questions about their nation's energy futures, and they must assess a number of options and energy strategies taking many factors into account. Many of the major issues were addressed at an international symposium convened in Vienna by the IAEA and nine other international organizations in late 1995. *(See box.)*

In opening the symposium, IAEA Director General Hans Blix surveyed the overall global energy scene. He noted that fossil fuels are expected to continue to dominate global energy supply, with solar power, wind power, biomass and other renewables projected to play valuable yet minor roles. Nuclear power's contribution, which now stands at about 7% of the world's commercial energy and 17% of its electricity, is projected to remain significant.

He further pointed out some of the complexities facing today's energy planners and decision-makers, particularly in the electricity sector. They must take into account a range of factors related to the entire fuel cycle of the energy source — including their technical and economic performance and their impact on health and the environment. While costs remain a key factor, they must be measured in many comparative ways — including assessing the costs for those countries suffering from a chronic *under-supply* of electricity.

Mr.Bennett is Head of the IAEA's Planning and Economic Studies Section in the Division of Nuclear Power, and Mr. Derrough is a staff member of the Section.

The types of analysis now required, he said, require the design of approaches that incorporate all relevant elements into a comprehensive comparative assessment of different options and strategies, and to develop enhanced databases, analytical methodologies, and other decision-aiding tools upon which policy makers can rely to support their decisions. International organizations have an important role to play in helping to meet these challenges, he pointed out.

As part of its efforts to assist national energy authorities in analyzing and planning their energy and electricity systems, the IAEA is conducting a programme covering comparative assessment and methodologies that will objectively support decision-making processes. This article reviews efforts in the context of the major electricity and related issues addressed at the 1995 international symposium. It includes highlights of keynote addresses and selected major points addressed during six technical sessions.

Highlights from keynote addresses

Dr. E. Andreta, European Commission. He stressed the importance of understanding the linkages between electricity, environment, and the economy (the E3 linkages). The relationships are very complex, and it is not possible to manage the whole electricity system without very reliable and efficient technologies, on one side, and without comprehensive management and planning tools on the other side. The EC has developed a large set of energy models for planning sustainable development of energy and electricity supplies. The databases and models developed within the inter-agency DECADES project initiated by the IAEA are another positive contribution, one that points out the necessity of global co-operation in this field. *(See box.)*

Dr. R. Stern, World Bank. Primary energy consumption in developing countries is expected to equal that in OECD countries by the year 2000, and by the year 2030 to be 2.5 times greater than OECD consumption. The World Bank estimates that the investment needs of the electric power sector alone will be of the order of US $150 billion per year. Financing this investment will require a mix of national resources and international capital. The World Bank recognizes that the appropriate mix of policy mechanisms and technology choices will depend on the situation of each country, its resource endowment, and the inevitable trade-offs required to achieve economic and environmental objectives.

For many countries, natural gas is a very attractive fuel. The difficulty is that gas is not always available where it is needed; hence, gas trade via pipelines or as liquefied natural gas (LNG) is essential. This will require large investments, a great deal of international co-operation, and a long time for development. Dr. Stern noted that the burning of natural gas produces relatively low amounts of CO_2 compared to the burning of coal. However, the greenhouse gas effect of unburned natural gas (methane) is some 30 times greater than that of CO_2; therefore, roughly a 5% leakage rate in a gas pipeline would negate the benefits in CO_2 abatement achieved by substituting gas for coal in a power plant.

Ms. J. Aloisi de Larderel, Industry and Environment Department of the United Nations Environment Programme (UNEP). While electricity is available to virtually 100% of the population in industrialized countries, an estimated 2 billion people in developing countries have no access to electricity. Thus, there is still a huge potential for electrification in developing countries. Electricity provides the possibility of clean and efficient energy use in households, transport, and industry. However, the massive provision of electricity to growing populations with increasing standards of living and expanding industries introduces the risk of potentially serious environmental impacts. Therefore, UNEP's primary role in the area of energy is to foster environmental awareness and to encourage greater incorporation of environmental issues into energy planning and policy.

Dr. A. Tcheknavorian-Asenbauer, United Nations Industrial Development Organization (UNIDO). UNIDO estimates that the industrialization process in developing countries — where 60% of the world's projected population growth will take place — will require a tripling of energy supplies by the year 2025.

Cost-effective improvements in the existing equipment using energy, and the application of good housekeeping measures in industries can result in efficiency gains of up to 40%, and this can be achieved with small to moderate investments. Process improvements, although much more capital intensive, can achieve energy savings of more than 50%. Thus, decision makers need to examine all available options for energy conservation and efficiency in terms of their potential for helping to meet the country's economic and environmental goals.

About the International Symposium

The Symposium on Electricity, Health and the Environment: Comparative Assessment in Support of Decision Making was held 16-19 October 1995, in Vienna, Austria. It was organized jointly by the IAEA and nine other international organizations: the European Commission (EC), the Economic and Social Commission for Asia and the Pacific (ESCAP), the International Bank for Reconstruction and Development (IBRD), the International Institute for Applied Systems Analysis (IIASA), the Organization of Petroleum Exporting Countries (OPEC), the Nuclear Energy Agency of the Organization for Economic Co-operation and Development (OECD/NEA), the United Nations Environment Program (UNEP), the United Nations Industrial Development Organization (UNIDO), and the World Meteorological Organization (WMO). Some 200 experts from 53 countries and 16 different organizations took part.

The Symposium was convened as part of the inter-agency project called DECADES, which the IAEA and its partner organizations are sponsoring. The project focuses on databases and methodologies for comparative assessment of different energy sources for electricity generation. Its main objective is to strengthen information sharing and co-operation between interested and affected parties in the field of electricity demand analysis and supply planning, aiming towards implementing sustainable policies in the power sector, taking into account economic, social, health and environmental aspects. Sessions addressed the following topics: key issues in the decision making process; assessment of health and environmental impacts; integrated framework for comparative assessment; implementation of comparative assessment; country case studies; and comparative assessment in decision making. A closing roundtable focused on challenges for global co-operation aiming towards implementation of sustainable electricity policies. In addition to the main sessions, poster presentations illustrated results from comparative assessment studies carried out in different countries, and software demonstrations provided opportunities for participants to gain information about state-of-the-art computer tools, databases, and analytical models used in decision support studies.

Proceedings of the Symposium are being published by the IAEA.

New and renewable energies, such as solar power, biomass, and small hydropower should be examined as options for decentralized supply of electricity to rural areas, which, due to the low population density, are expensive to supply from the central grid. Dr. Tcheknavorian stressed the important role that biomass, particularly wood, represents as an energy resource for rural populations and also for local industries. She noted that biomass provides over 50% of the industrial energy in Africa. However, the use of biomass is often associated with inefficient conversion processes and the collection of fuel wood can lead to deforestation.

Also, industrialized countries should assist developing ones by transferring technologies that are well adapted to the needs and situations in developing countries. In order to assess and compare various energy systems, decision makers need to define technology transfer as a strategic component of an energy programme. Thus, the extent to which various technologies can be absorbed, and the time and cost needed for that process, need to be examined. Finally, the main lesson that UNIDO has learned through its experience in developing countries is that, in order to contribute to sustainable socio-economic development, decisions on energy systems must take into account the specific situation in the country in which they will be implemented.

Dr. L. Olsson, World Meteorological Organization (WMO). In presenting a keynote address on behalf of Prof. Obasi, Secretary General of WMO, he reviewed issues related to energy and climate change. Production and use of energy has a complex impact on the environment, including an impact on climate, and the need for energy is normally directly related to climate and weather. Also, many energy-related activities, e.g. production of energy from biomass, hydropower, and other renewable sources, are based on resources that are extremely sensitive to climate. Global concern over potential climate change has increased the need for environmental impact assessments. In order to ensure a fair judgement of various energy systems, it is of utmost importance to make available relevant information, and it is essential to take a non-biased attitude in assessing scientific, technological, and socio-economic development. The DECADES project is making an important contribution towards this objective.

Highlights of technical sessions

Session 1: Key Issues in the Decision-making Process. Chaired by Dr. Rajendra Pachauri, Director of the Tata Energy Research Institute in India, the session focused on the wide range of issues of concern to decision makers in various regions. Papers illustrated that there may be greatly different priorities according to the level of social, economic, and industrial development in a given country. Presentations included those by Dr. K. Leydon, of the EC; Dr. H. Khatib, speaking on behalf of the World Energy Council's Committee on Energy Issues in Developing Countries; Mr. L. D. Ryabev and Mr. Y.F. Chernilyn of Russia; Ms. J. Ellis and Mr. S. Peake of the International Energy Agency of the OECD; and Mr. R. Lanari, Canada. A number of important points were addressed.

- Member countries of the European Union are dependent on imports for 50% or more of their energy, and this likely will rise to about 70%, Dr. Leydon noted. The challenge to any economist is how to meet the environmental goals and, at the same time, avoid raising the cost of energy as a factor in production. He stressed that it will be no easy task in an evolving geopolitical situation to develop new energy services in response to changing needs; to harness energy efficiency; and to develop new technologies and products. The decision-making framework has to properly reflect the complexity of the choices to be made.
- Developing countries, particularly those in the low income category, are concerned about cost more than anything else, Dr. Khatib said. Therefore, they try to utilize available local fuels, irrespective of their quality, whenever possible. Also, priority is given to technologies requiring low investment, which may lead to the use of local technologies having less efficiency than state-of-the-art technologies. In most instances, these countries cannot afford the extra investment to install pollution abatement systems. However, developing countries are becoming increasingly concerned with environmental questions, and they are trying to reduce pollution, in particular where it is causing local impacts.
- The two largest developing countries, China and India, have populations of 1175 million and 900 million, respectively; a combined population of 2075 million which is almost half the total of all developing countries, Dr. Khatib noted. The growth potential of electricity supply in both countries is very high, and both have large coal reserves. Therefore, both countries will continue to depend on coal as their major fuel for electricity generation for decades to come. Indeed, all developing countries with reasonable levels of commercially viable coal reserves will favour coal as their main fuel for electricity generation. To minimize the environmental consequences of more coal burning, clean coal technologies need to be promoted in developing countries.

INSIDE
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Cattle killer meets its match

Cattle normally play a crucial role in rural economies of developing countries, providing crop manure, domestic fuel and hides, as well as meat and milk, while the bullock is the tractor in the field and the engine of transportation. But in a wide belt across central and southern Africa and on Zanzibar's main island Unguja, livestock rearing is seriously hampered because the tsetse fly spreads disease to the animals. Numerous costly efforts to eradicate tsetse - using traps, insecticides, and other conventional methods - have failed thus far. Now it seems that eradication is possible, at least on isolated Zanzibar.

Blood sampling from cattle to monitor disease transmission. (Credit: U. Feldmann)

Unguja and a few tiny satellite islands make up Zanzibar, 35 kilometres east of continental Africa. It joined the United Republic of Tanzania in 1964. A lone fly species lives on Unguja. Apart from it, the island has ideal conditions for cattle - lush vegetation, gently undulating terrain, reliable and ample rainfall. Yet some 10,000 live animals plus US$250,000 of milk products must be imported each year to supplement the low per capita intake of protein on Unguja.

Tsetse flies (*Glossina* species) live only on blood. Some species carry sleeping sickness to humans, others a similar disease, *nagana*, to animals caused by single celled

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Barley climbs the Andes

Across the high Andean plateau in Peru and Bolivia, the diets of the impoverished peasant communities remain inadequate. Staple foodgrains cannot be grown because of the oxygen-short conditions, the stress of daily temperature variations and high ultra violet exposure under cloudless skys. An early barley, perhaps introduced from Europe many centuries ago, does manage to survive. But it is poorly acclimatized and its yields are extremely low.

The plateau is mostly a flat plain, 3400-4000 metres above sea level. Local farmers cultivate protein-rich Amaranthus, Quinaoa,varieties of potatoes and faba bean which can fix atmospheric nitrogen and naturally fertilize the soil, much the same as the ancient Incas did. Soon they may well have a superior barley.

The IAEA has helped Peru develop its capability to apply nuclear techniques and these are now being used to breed new high-yielding grain varieties with built-in stress resistance. They could not only increase the food security of the high Andes, but promote sustainable grain production on a large scale as well. A mutant vari-

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Better feeds make bountiful breeds

Increasingly throughout rural areas of central and western Java, small groups of people, mainly women, may be seen mixing what appears to be large loads of unlovely and smelly muck. In fact, they are doing something both economically and scientifically sound, making Urea-Molasses-Multinutrient Blocks (UMMBs) to feed to their ruminant animals - buffalo, cattle, goats and sheep - and provide them with some essential nutrients they lack.

Cornelia Hendratno received special training in nuclear and related techniques in animal production at the Agency's laboratory in Seibersdorf, and led the BATAN research group that developed the supplemental feed block. She was responsible for the initial field trials that brought experimental ingredients to rural areas where she worked with villagers to knead bricks into forms. When early results of the feeds were clear she encouraged the Ministry of Agriculture to take over an extension role. Ms. Hendratno was also a key link with the Agency, as technical coordinator and then principal investigator in the IAEA projects. She now heads BATAN's Animal Nutrition Research Group.

Shortages of quality feed for livestock is common throughout much of Asia, where there is little land set aside as pasture and few forage crops are grown. Most cattle are kept by small farmers in herds of 2 or 3, rarely more than a dozen, in mixed-enterprises that include crop cultivation. They forage on what they can find, such grass and straw by roads and fields, and residues of agriculture and food production. Yields and quality of milk and meat are low.

Improving the quality of feed for ruminants in a way that small farmers can afford in terms of cash and labour was the task taken up in the early 1980s by scientists led by Ms.Cornelia Hendratno at the Centre for Application of Isotopes and Radiation, which is part of Indonesia's Atomic Energy Agency (BATAN). They had funds from the UN Development Programme (UNDP) and the infrastructure and skills developed over many years with help from the IAEA. The technique involves the use of benign tracer isotopes that reveal the fate of feed constituents in the digestive system of ruminants.

The multinutrient block, a mixture of feeds and vitamins, that Ms. Hendratno and her team developed after years of lab research and animal tests has been received enthusiastically by Java's villages. It has stimulated 30% increases in milk yield and over 100% increases in growth rates of beef cattle, goats and sheep. Perhaps the key to its appeal is that it uses locally available feedstuffs - straw, rice stubble and bran, cottonseed cake, waste from fish processing and even poultry litter - mixed with appropriate amounts of urea, molasses and various minerals.

The mixture is pressed into moulds and dried to make brick-like blocks. A key feature of a block is that it must have a consistency that enables an animal to lick it but prevents it from eating it all at once. This has been successfully worked out for various formulations so that once the mixture is prepared by the villagers it is not necessary to thumb-test each brick.

The urea provides nitrogen proteins for growth; the molasses gives the energy and sulphur helps utilize the nitrogen and build up microbial protein that provides amino acids. Other minerals, like calcium and phosphorus essential for lactating animals, can also be added. Each block is made large enough to avoid the labour of too frequent replenishment and enabling adequate stocks to be made. The aim is that each animal licks 500-700 grams of it per day on average.

During earlier field trials to assess the efficacy of various formulations in local animals, Ms. Hendratno and her team found that community women in particular wanted to be trained to mix and make the blocks. Farming families soon joined in cooperatives to produce and use them. In the past few years the Ministry of Agriculture has taken on the task of extension work, promoting the technique, teaching villagers to make bricks with locally available materials, and encouraging local co-operative schemes.

Under a Agency technical co-operation project launched in 1994, BATAN started training courses

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Local women manufacture UMMB's in Indonesia. (Credit: C. Hendratno)

Floating rice and soaring sorghum

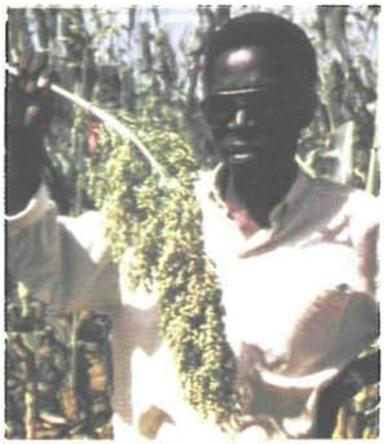
Smallholder agriculture is the backbone of Mali's economy. But yields of staples - millet, sorghum, rice, maize and fonio - have not kept up with population growth, and the rising cost of cereal imports now consumes 6.5% of GDP. Crop improvement has depended almost solely on seed selection by individual farmers, while systematic plant breeding has only recently arrived. Breeding more productive rice and sorghum is the principal challenge.

Malian scientists have now produced rice and sorghum mutants that could benefit smallholders and the national economy if widely grown. But until recently strains remained in the laboratory. Now, with new initiatives in Agency technical co-operation, the new mutant varieties will be taken to the farmers through a government extension programme that involves community participation.

In the expansive floodplains of the Niger River in Mali farmers have grown rice for many centuries. This peculiar "African rice", or *Oryza glaberrima*, evolved here before the arrival of humans. Its make-up includes genetic traits essential for survival. Its stalk grows in pace with the rising water, keeping its panicle (seed head) afloat; it can cope with dehydration stress after the waters recede; and it shatters seed when mature.

Mali's native sorghum relies exclusively on rainfall and has traits that give it resistance to drought. Farmers grow varieties that are extremely tall, sometimes 3 1/2 metres because the stalk has many economically important uses - as cattle feed and roof thatch, for making mats and even the small huts in which grain is stored.

The challenge for plant breeders is to improve productivity of these crops, while conserving their essential traits. Malian scientists Fousseyni Cisse and Al Housseni Bretaudeau led research teams to find mutant varieties of rice and sorghum at the *Institut d'Economie Rural* and *Institut Polytechnique Rural*, respectively. Under a recently completed FAO/IAEA Coordinated Research Programme (CRP) funded by Italy and designed to help **improve local and basic food**



Unusually long seed head of sorghum displayed by Mali technician. (Credit: B. Ahloowalia)

crops of Africa they irradiated traditional varieties with gamma rays according to the prescribed procedures. IAEA technical co-operation had already provided training and equipment to enable the two national scientific institutions to have the capacity to apply nuclear techniques such as mutation breeding, to improve yields and other enhanced characteristics of traditional food crops.

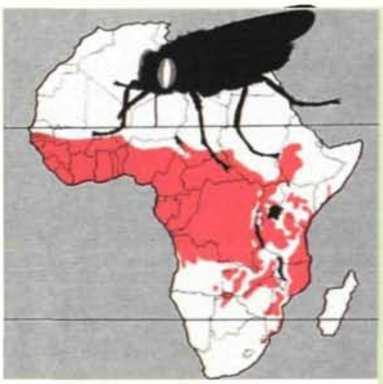
During the five years of the CRP, Cisse's rice team was not able to identify a non-shattering variety, which was its aim, but it did develop some new types with white color characteristics and high yields. White rice in Africa fetches double the price of red; so for farmers the colour alone means an income hike, with high yield a bonus. Bretaudeau's team obtained sorghum mutants that grow tall but do not lodge, and some with increased seed; one with 50 cm panicles, twice as long as usual (see photo).

These preliminary successes prompted the Agency to launch a Technical Co-operation Model Project to continue the mutation breeding activities, to carry the achievements of the scientists out into field trials that could eventually benefit farmers and to expand related research and development capability in plant tissue culture by setting up a dedicated laboratory along with top level training in these techniques.

Within the multi-purpose Model Project, field performance trials on mutants of both rice and sorghum crops have already started. So have some soil trials, using stable nitrogen (N^{15}) isotope techniques developed by the FAO/ IAEA Joint Division, mainly to determine optimal use of fertilizer because every new genotype has its own nutritional requirements. Further soil/plant density trials will establish other parameters such as how many plants should be grown in different areas.

This effort reflects an impressive array of high technology and sophisticated training, but can it really help the poor local farmer who probably can't read? The experts think so, and the Model Project approach is intended to focus technology and its benefits on the end-user. Initial field tests show increases of 10% in sorghum production and 15% in rice, and the demonstration phase is being expanded significantly this year and next. New plant breeding techniques that merge conventional breeding with new bio-technical approaches and mutation techniques are improving the odds that the new varieties can successfully compete with native breeds. A comprehensive "package"of agronomic practices will help guide farmers to higher yields using fertilizer management techniques resulting from soil trials using stable nitrogen (N^{15}) isotope techniques. One such practice would incorporate nitrogen fixing legumes (see related story on Biofertilizer in Zimbabwe) in the cropping system for a low-cost, or no-cost alternative nitrogen fertilizer

The extension services of the Ministry of Agriculture will take these "best" practices to the farmers to train and demonstrate their benefits. With the World Bank now supporting a national facility to reproduce seeds on a commercial scale, Mali's farmers could soon begin to realize the dream of two research scientists who were inspired to push back the limitations of native cultivars and make an important contribution to the food security of their countrymen.



ganisms called trypanosomes. The single species (*G. austeni*) on the island attacks only animals. Nagana, first reported in Unguja early this century, has restricted and ravaged the 1,650 square kilometre island's herds and until recently up to 80% of the remaining cattle were infected.

Initial efforts to eradicate the fly-using environmentally friendly methods-began over 20 years ago with a research programme in mainland Tanzania funded by the US Agency for International Development. A laboratory and facilities for mass-rearing of tsetses were introduced at Tanga. Significant experience was gained in this effort but it eventually proved unsustainable. Since then a series of activities on Zanzibar involving bilateral and multilateral assistance have used conventional methods to substantially reduce fly numbers and contain their movement.

Conditions thus seemed promising for eradication when the IAEA Model Project was launched in 1994. Fly density had been drastically reduced, in some areas to levels below detectability by trap surveys. Re-infestation was unlikely because it is far from the mainland. The tsetse fly reservoirs in Unguja were mainly in three forests in the south; and a broad enough belt of mainly rice paddies separated these from the north of the island. New techniques developed in projects against other pest insects, such as aerial release, could be introduced on Zanzibar.

The IAEA Model Project is relying on SIT, the Sterile Insect Technique, to mass-rear and release sterilized male flies in sufficient numbers to challenge the fertile wild males as mates for the wild females. SIT is well advanced and has been effectively used against fruitflies in both North and South America. But its application against other insects, such as the tsetse, is an innovation being fostered in the Technical Co-operation Programme with the support of the Joint FAO/IAEA Division.

After just two years of sterile male releases, females routinely caught in the wild already show a high ratio of infertility, expected to reach 65% in the first quarter of this year. Major advances are being made (see box) in rearing and sex identification systems. To promote the approach the IAEA convened a four-week SIT training course/seminar in Unguja late in 1995 for scientists from other African countries affected by tsetse.

The Agency first got involved in helping Zanzibar back in 1983 with the training of Tanzanian scientists at IAEA's Seibersdorf laboratory in mass rearing the Unguja

The Sterile Insect Technique

SIT involves rearing, sterilizing, and releasing male flies of the target species so that they vastly outnumber wild males in the area. The wild females they mate with will not be able to lay fertile eggs. Over time the reproduction of the wild population dwindles and eventually dies out. One common problem is re-infestation from outside the target area.

A unique challenge **with tsetse flies is that they must be fed with blood. It is not possible to maintain large enough breeding colonies fed on living animals, and the flies normally do not feed on blood any way but through skin. Scientists at the IAEA lab in Seibersdorf solved the twin problem in the early 1980s with a technique that can maintain insects on a factory scale by giving them bloodmeals through an artificial membrane, thus fooling the flies into thinking they are feeding on live animals.**

On the horizon **is an automated computer controlled system that eliminates the labour intensive steps of chilling newly hatched flies, manually separating males and females, and then thawing them again. This procedure currently takes over 40% of the time necessary to produce sterile males. Chilling weakens both sexes. Overchilling can kill or render females sterile. Physical handling can damage individuals. The new system will sex the flies in flight, as they emerge from hatching or mating areas, and guide them into separate cages. It could be ready for use within three years. It would improve fly quality and cut time and effort from the four skilled people now needed to breed 100,000 flies, to half a person to breed a million.**

Further **ahead is the prospect of genetic manipulation of tsetse so that colony females would produce only males, or the two genders would react differently to temperature in the pupal stage and one or other could be killed by simple warming or cooling. Fewer females could produce more males.**

tsetse species, using a *membrane* feeding technique developed there. Facilities in Tanga were systematically improved and extended so that by the end of 1995, with a colony of 400,000 females, it housed the world's largest tsetse production system. The colony will soon be 500,000, allowing for the release of 50,000 (60,000 with back-up from Seibersdorf) sterile males each week. Thanks to the support of several donors, the project is well on its way toward a successful conclusion.

To rebuild Zanzibar's herds of mixed livestock, family based farming is now being expanded. Farmers in areas that were until recently infested now have the opportunity to obtain cattle through a government programme offering very attractive loans. Government initiatives to inspire family-based herds, in a sustainable and environmental friendly manner, are based on the very real prospect of the tsetse being eradicated by the end of the IAEA Model Project in 1997.

SIT will be deployed throughout Unguja. But the early focus has been on the southern forest pockets - Jozani, Central Muyuni and Coastal Muyuni - which are inaccessible to other techniques. Therefore, since September 1994 sterile male releases have been exclusively by air. Experience, in Zimbabwe and elsewhere, shows insecticide spraying by air is often ineffective and hazardous. But the 30 milligram flies are not blown off-target by light winds and thermal currents, so the aircraft can fly at a safe height above the forest canopy, and effective air drops can be made throughout the day instead of only at night when the ground gets cool.

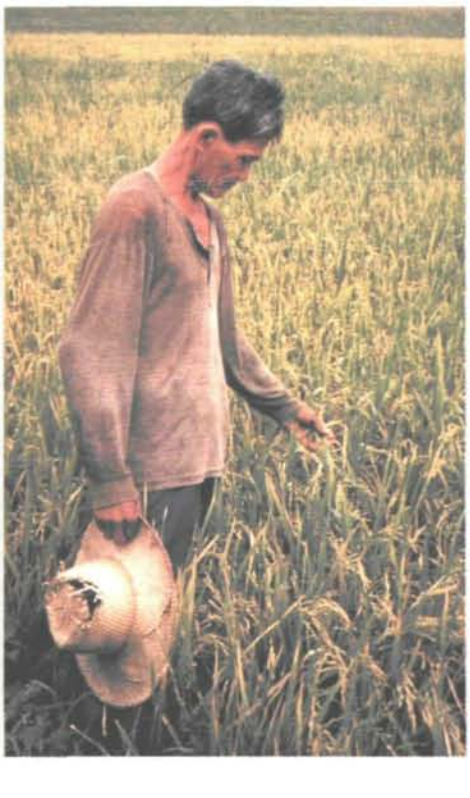
National authorities have provided scientists, technicians, infrastructure, as well as cash to the project; they also integrated it with national development plans so that its benefits reach those who will use the tsetse-free land. The Zanzibar programme is developing an integrated smallholder farm system, with help from the International Fund for Agricultural Development (IFAD), to ensure that farm families are the principal beneficiaries and that freed land is used sustainably

The atom and food production

Despite major advances and "revolutions" in agricultural production, many countries still face enormous obstacles in meeting their current demand for food. In Africa for example, projected demand will require a tripling of the current agricultural output in the next 30 years. A country's capacity to produce surplus food remains a basic distinction between developed and developing countries. As the scramble for control of global resources intensifies, the gap grows wider.

How will the developing world's farmers meet these staggering requirements for more food? What improvements in agricultural systems will permit doubling let alone a tripling of output?

These increases will only occur if agricultural resources are expanded or more productive resources become available in agricultural systems. Such "resources" include land, water, the human knowledge base, technology and institutional support. The food and agricultural programme of the IAEA is operated jointly with FAO to assist Member States in using nuclear techniques to improve both the *quality* and *quantity* of agricultural resources. The availability of agricultural land and water are being expanded through environmentally sustainable approaches that include SIT technology to biologically eradicate pests like the Tsetse fly that severely limits animal production across vast areas of Africa; and isotopic techniques to study, irrigation and ground water dynamics. The quality of agricultural resources is being enhanced through the introduction of more productive technologies: mutation breeding is a technique to create new plant characteristics such as drought resistance or higher yield. Improved farming practices such as the use of rhizobia to inoculate crops and improve soil fertility is an environmentally safe and economical alternative to conventional fertilizers. Soil moisture and nutrient management are fostered by agro-chemical techniques that improve crop yield and food quality. In the areas of animal production and health, nuclear techniques have unlocked many secrets of the biological processes responsible for growth, health and reproduction of farm animals. The growing importance of food preservation techniques such as irradiation is reinforced by the loss of one quarter of world's food production after harvest.



The IAEA's Technical Co-operation activities in agriculture play a small but increasingly catalytic role in sustainable agricultural development. This edition of *Inside TC* illustrates how a new partnership is being forged between scientists and development managers to empower farmers through a variety of specialized techniques, improved practices and agricultural knowledge systems.

ety of barley, ***UNA-La Molina 95***, began field testing last May and is now being multiplied at several sites in the Peruvian highlands.

Plant breeding is exacting. It requires persistence and care and, most of all, time. Irradiation of seeds with gamma rays can help to accelerate the process and leads to changes in the genetic traits of the plants which are inherited. The story of the new barley mutant goes back more than 15 years to when plant breeder Marino Romero Loli became head of the cereals department of the national agriculture university in La Molina. A son of the high plateau himself, Romero Loli set course to produce, by mutation, new varieties of barley and wheat that would be viable in the highlands.

His initial aim was to improve the diet, health and economy of the highland communities. But with some three million hectares of the plateau (in Peru and Bolivia) considered arable, the longer term prospect of intensive commercial cultivation was inviting too. The task may have seemed whimsical because the first essential ingredient to produce a mutant, local parent material, was missing - no wheat or oats at all and the unacclimatized barley was clearly unsuitable. But there was early support from outside and the FAO/IAEA Joint Division became involved shortly thereafter.

The breeding strategy began with field testing a wide collection of wheat, barley and oat germplasm. Over the years some 10,000 varieties provided by international and national centres all over the world were grown in tiny beds to see which did best in the inhospitable climate. From those that showed most promise Romero Loli's team produced a new barley variety using conventional breeding methods. It went through the required field growing and selecting for eight generations, and was released in 1990 under the name ***Buena Vista.***

The scene was set for mutation breeding using radiation. Peru's nuclear infrastructure, equipment and mutation breeding skills had already been systematically improved through IAEA technical assistance for more than a decade. A US donation of $1.5 million for the region enabled the Agency to help Peru beyond mere equipment and training. Plant breeding at La Molina was co-ordinated with work in other FAO/IAEA activities including a regional programme for **Improvement of Cereals through Mutation Breeding in Latin America**, and a related Coordinated Research Programme.

Inspecting a barley field near Huancayo. From left to right: C. Ampuero (IPEN); B. Radischat(IAEA); L. Gamara (IPEN); and M. Romero Loli (Agricultural Univeristy, La Molina). (Credit: M. Maluszynski)

The La Molina team irradiated *Buena Vista* seeds and obtained the mutant variety UNA-La Molina 95. The mutant has three main advantages over the parent. It matures some three weeks earlier - which will enable it to reach the seed ripening stage when the dry season arrives. It is shorter - a protection against being flattened by wind or hail. It produces a naked (huskless) grain with higher protein content which is easier to both cook and feed to animals.

The three new traits make the mutant very promising. But the proof of viability is in the growing. When the ongoing multiplication phase produces two to three tons of barley seeds (expected this year) they will be delivered to demonstration plots of selected farmers who have a good reputation in villages. They will grow it together with the previous (parent) variety. Only then can the quality of the mutant be gauged. It will take longer, 2-3 years, to demonstrate true success - after farmers have grown it on many thousands of hectares. But chances look good that the 21st Century may begin with the first cultivable Andean grain and new opportunities for agricultural development.

Meanwhile the private sector has also recognized the promise of mutation breeding. A Peruvian brewery company *Malteria Lima SA* is providing funds and managerial help to the agricultural university at La Molina to multiply the seeds of the mutant variety of barley it has developed and to distribute them to the selected farmers in the high plateau even though it has different characteristics from the barley used for beer. UNA-La Molina 95 is huskless and has a high protein content. Brewers seek barley with protein content as low as possible, and therefore always with husks. Malteria's reasoning is that the other traits - early maturation and short stature - promise intensive high-input cultivation at high altitude. If the '95' variety is successful 3000-plus metres above sea level and in other hostile conditions, then yet another variety (husked and low protein) could well be found in the same way.

In Brief: Updates of stories and news events

AGFAX: Reaching Zimbabwe Farmers

"The interview on SIT and Tsetse was a very useful eye-opener, especially considering that in Zimbabwe, the tsetse flies are very troublesome. This interview was translated into a vernacular programme broadcast on Radio 2." — Statement by Zimbabwe Broadcasting Corporation

The use of technology for development depends on attitudes and these are influenced by information and education. The Department of Technical Co-operation (TC) is increasing public awareness of its Model Projects activities through a series of contributions to the AGFAX media service. Articles for the press and interviews with IAEA staff on key agricultural issues are recorded and distributed on a monthly basis to leading radio stations and newspapers in anglophone Africa and to major European and North American organizations broadcasting worldwide. The Sterile Insect Technique (SIT) to eradicate tsetse flies, the improvement of african rice by mutation breeding and nuclear techniques analysis of nitrogen in crops are among the range of topics covered.

You or your colleagues could help us reach broader audiences. Upon request recorded copies and full transcripts of these interviews are available for use by national broadcasters free of charge. Each audio cassette comprising a five minute feature is edited and ready to broadcast. For more information, contact the IAEA TC Programme Co-ordination Section.

AGFAX is produced by World Radio for Environment (WREN), a media organization based in the UK.

Mutated Rice Gains Ground in Asia

Nine varieties of early season rice, obtained by induced mutation of locally grown varieties, were officially released and cultivated on 598,100 hectares in five provinces along the Yangtze River in China last year. The mutant varieties now cover about 11% of the total 5.5 million hectares of rice growing area in these provinces. The performance of each mutant variety varied depending on the agroclimatic conditions in particular provinces. According to data collected during the multilocation trial, yield increases per hectare for the nine mutant varieties was on average 440 kg higher than for the control varieties.

Increasing rice yields is a key objective throughout Asia. (Credit: M. Maluszynski)

The Chinese National Rice Research Institute estimates a total yield increase of 263,000 tonnes in the cultivated area. At a market price of US $200 per tonne the gain to farmers could reach over US$ 50 million. The extension process was actively supported by seed companies at the provincial, municipal and county level. Because the seed multiplication programme has been so successfully implemented, an extension area of 990,000 hectares is planned for 1996.

In Myanmar, according to recent information received from the Ministry of Agriculture, the rice mutant *Shwewartun* showed improved yield, grain quality and earliness compared to its parent variety. Over the period 1990 to 1993 the mutant variety was grown in over 2 million acres or 17% of the total rice area sown.

Close collaboration - with national institutes in both China and Myanmar made possible through co-ordinated research programmes and technical assistance projects - contributed to the development of these successful mutant varieties. The experience gained from these projects is contributing to similar mutation breeding in other regions (see related story "Floating Rice and Soaring Sorghum").

RCA Recognized for Excellence

Late last year the Joint Inspection Unit, an independent investigatory body of the UN, compared field level impacts and results of 10 U.N. sponsored intercountry projects in the Asia and Pacific Region. One of those selected was the RCA project to increase the use of nuclear technology in regional industries and encourage regional industrial competitiveness (see "Pioneers of regional cooperation" - *Inside TC*, December 1995). This IAEA-supported project was rated number one in the evaluation with a score of 96 out of 100 points, one of the best reviews ever made for a project in the field of science and technology. The strong commitment of national counterparts and the readiness of participating governments to collaborate actively with the private sector were identified as particular strengths of the project, and the RCA network of cooperating member states was viewed as a model for Technical Cooperation among Developing Countries (TCDC). This project was cofinanced with the United Nations Development Programme (UNDP) and contributions from Australia, China, Indonesia, Japan, Philippines, Korea, Malaysia, New Zealand and Thailand. RCA Members are now preparing a third generation project for submission to the Agency and UNDP that will employ isotope and radiation technologies for better management of the environment, natural resources and further promotion of industrial growth.

Zimbabwe's smallholders to benefit from biofertilizer

Many developing countries have the capability to use selected strains of legume root-nodule bacteria to produce nitrogen, the most important plant nutrient. But in most, the benefits have been reaped by larger farms growing cash crops such as soybean. Subsistence growers, who might gain most from the technology, have largely missed out. But now up to half a million smallholders in Zimbabwe will gain access to the technology through an Agency technical co-operation Model Project set to begin in 1997.

Bacteria of the rhizobium "family" have been called Nature's gift to sustainable agriculture They form nodules in the roots of legumes and convert nitrogen from the air into the form usable by plants in a process called "nitrogen fixation". It is a similar process to the chemical one used by industry to manufacture urea fertilizer, but root-nodules do it for free. Though nodulation occurs only in symbiotic relationship with legume plants, the nitrogen they 'fix' is sufficient to nourish a subsequent non-leguminous crop. In recent years the technology to mass produce specific 'inoculants' of rhizobia strains has matured. Indeed the biological route now provides more than a third of all nitrogen used in world agriculture, but nearly all of that is consumed either in developed countries or large commercial farms in the developing world.

Nearly 25 to 30 Agency agricultural projects around the world now have a rhizobial component. The first Model Project dedicated to it was launched last year in Bangladesh (see *Inside TC*, September 1995). It is developing commercial scale production of inoculant. Assisted by IAEA projects since 1988, and using the stable isotope N^{15} technique largely developed by the Joint FAO/ IAEA Division, the Bangladesh Institute of Nuclear Agriculture (BINA) has identified rhizobial strains and matching varieties of legumes that together would best fix nitrogen in local soils.

The new project, proposed for 1997/98, in Zimbabwe will use the N^{15} technique to screen and select efficient rhizobia to maximize yields of important legume varieties grown locally, and possibly also obtain new varieties using radiation mutation breeding techniques. Zimbabwe already has a large factory to multiply rhizobia and put them in medium for distribution to commercial farmers, and its production could be expanded to meet the needs of small-scale farmers for inoculants.

Zimbabwe's Country Programme Framework (CPF), drawn up by the IAEA and the Government, is focussed on a limited number of technical co-operation priority activities where the technologies have demonstrable value and the government is committed to developing essential infrastructure. Development of biological nitrogen fixation for subsistence farmers in the communal areas is one such activity. Levels of crop production in the small-scale farming sector of Zimbabwe are very low, mainly due to low soil fertility - particularly nitrogen and phosphorus. The CPF confirmed that the technical capability and counterpart structure to undertake this activity is strong and that previous technical co-operation work has developed data on nitrogen fixation using three locally grown legumes. A multidisciplinary research team has already been trained and prepared to undertake the task.

Given these promising conditions and drawing upon the ongoing experience in Bangladesh, the TC Department is confident that the project being formulated will make a significant contribution to food production and small farm prosperity in rural Zimbabwe.

Pioneered by the Joint Division of the FAO and the IAEA, the N^{15} technique has proven to be a unique tool in assessing the amounts of nitrogen derived from air, soil and added fertilizer. It is relatively simple and requires growing the nitrogen-fixing crop together with a non-fixing crop. The major advantage is that it provides a quantitative and integrated measure of the nitrogen fixed - during different periods, conditions and soil types. It is preferred to non-isotopic methods because it gives detailed understanding of factors that influence the fixation in various legumes, and therefore the "yield", particularly the effects of inoculation with an elite strain of rhizobia.

Better feeds (from page 2)

last year in three islands (East Java, South Sulawesi and West Sumatra,) and field-testing of blocks with feed materials available in each region.

Meanwhile in West and Central Java, the Ministry has now taken the technology to villages across all districts. In addition to such extension activities, several hands-on training courses have been conducted for leaders of farmers groups One in West Java in 1995 brought together 236 farmers for three months. This course evaluated 395 dairy cows, 80 beef cattle, and 100 sheep. A similar one was completed in Central Java late last year and involves analysis of 180 animals. Cumulative results of field trials indicates that UMMB supplementation could increase monthly net income by 200% for dairy and beef cattle farmers and 100% for sheep farmers.

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The DECADES Project: Progress Report

At the symposium, Dr. B.A. Semenov — who until January 1996 served as IAEA Deputy Director General and Chairman of the Joint Steering Committee for the DECADES Project — reviewed the project's three major areas of work.* These cover databases, methodologies, and training and support for implementing comparative assessments.

Databases. A Reference Technology Data Base (RTDB) has been established, which runs on personal computers. It contains numerical, textual and visual information on the main characteristics of electricity generation technologies at different levels of production chains using fossil fuels, nuclear power, and renewable energy sources. Several hundreds of technologies are characterized by a detailed set of parameters, covering technical performance, costs, atmospheric emissions, wastes, and other environmental burdens. In parallel with the RTDB, some 15 countries have been assisted in implementing Country Specific Data Bases (CSDBs), using the RTDB computer system to store information about their electricity chain facilities. The CSDBs cover more than 1000 technologies.

Methodologies. Two main tasks had been undertaken on methodologies: 1) the preparation of a report describing already available computer tools for comparative assessment of electricity generation options and strategies; and, 2) the development of a new software package for electricity system analysis and planning (DECPAC).

The report on computer tools is based upon information provided by software developers from different countries and international organizations. The new software package, DECPAC, was developed with financial support from the United States and provides enhanced capabilities for integrating technical, economic, health and environmental aspects into electricity system expansion planning. It is linked with the RTDBs and CSDBs and enables analysis of costs, airborne emissions, solid wastes, and other health and environmental burdens of different electricity generation strategies. Some 12 teams from different countries are testing DECPAC for case studies, and their initial experience has shown that it is very useful to analysts and planners in the power sector, and that it meets a real need.

Training and Support. Training workshops are being organized at national, regional or interregional level. They involve users groups that have been established to promote exchange of information between users and the software developers. Work was started late in 1994 on a reference book integrating economic, social, health, and environmental issues into policy making for the power sector. The book's preparation is being led jointly by the IAEA and the World Bank, with important contributions by other DECADES organizations and national experts. It addresses issues such as integrated resource planning, external cost valuation and internalization, and multi-criteria analysis and decision-aiding tools. Expected to be completed by mid-1996, the book is intended to help policy makers in designing a comparative assessment framework adapted to specific requirements and objectives and in selecting appropriate computer tools for carrying out decision support studies.

Case studies. Dr. Semenov pointed out that more than 20 country case studies have been done on comparative assessment of alternative strategies and policies for the electrical power sector through the IAEA's Co-ordinated Research Programme (CRP). Participating in these studies are experts in the fields of electricity system analysis, macro-economics, and environmental impact assessment. The CRP has led to an increased recognition of the need to reconcile various concerns and priorities; for example, alleviating local and global environmental impacts and comparatively addressing economic, social, and security of supply issues.

Encouraging Results. Results obtained so far through DECADES are encouraging, Dr. Semenov said, and demonstrate the effectiveness of joint efforts by international organizations and national experts and institutes. High interest in the project has been shown by national experts, in particular from developing countries and countries in transition. While the project's first phase focuses on the comparison of different electricity supply options, some new directions have been identified, notably concerning demand-side technologies. Information on these technologies might be added to the databases, and an analysis of demand-side options might be incorporated into the DECPAC model. In this regard, Dr. Semenov noted that there has been close co-ordination with the project on establishing an "Environment Manual for Power Development", which has been managed by the World Bank. The results from this project could provide a basis for further enhancing DECADES tools.

Another area of greater future emphasis concerns comparative analysis of health and environmental impacts. The IAEA has done some work on establishing a database on Health and Environmental Impacts of Energy Systems, but more work is required to produce a tool that can be used in the comparative assessment process. The European Commission, in co-operation with national research institutes, also has done work on the external costs of energy systems. Also useful would be national studies using tools that have been developed to examine high-priority issues, such as the cost-effectiveness of different energy systems and measures for mitigating greenhouse gas emissions and other environmental burdens.

For an earlier report, see "Electricity, health, and the environment: The Decades Project", by Evelyne Bertel, *IAEA Bulletin*, Vol. 37, No. 2 (June 1995).

● Electricity's share in OECD energy use is expected to increase from 18% to over 21% by the year 2010. Electricity is an important source of CO_2 emissions in the OECD, accounting for 33% of total energy-related CO_2 emissions in 1993. Thus, in spite of the commitments taken in relation to the Framework Convention on Climate Change, total emissions from electricity production in OECD countries are expected to grow, since electricity demand is projected to increase by some 2.1% per annum up to 2010. However, the emissions will depend on the fuel mix, which differs greatly among OECD countries at present. Norway, for example, currently generates 99% of its electricity from renewable energies; Denmark uses coal for 87% of its electricity and the United Kingdom, United States, Australia, and Germany also rely on coal for the majority of their electricity generation. France, on the other hand, relies on nuclear power for some 75% of its electricity supply, while Italy generates the majority of its electricity from oil.

● In Canada, indigenous populations are being involved in the planning of a hydro-electric project. Through a process of intensive consultation with the indigenous Inuit populations, it was possible to identify a number of measures that could help to meet their concerns about potential impacts of the project. Also, the consultative process gave community members a measure of confidence and a feeling of control over the project, which they otherwise would not have felt. This process showed the importance of involving interested and affected parties as active participants in the decision-making process, and not merely as passive spectators.

Session 2: Assessment of Health and Environmental Impacts. Chaired by Prof. Mohan Munasinghe from Sri Lanka, this session examined the ongoing development of tools for assessing health and environmental impacts of energy chains for electricity generation. Presentations included those by Prof. B. Sørensen of Denmark; Prof. A. Markandya, Harvard University, United States; Dr. N. Pop-Jordanova, Former Yugoslav Republic of Macedonia; Ms. D. Lin, China; Ms. N.P. Villela, Brazil; and Dr. S. Morris, World Health Organization Collaborating Centre on Health and Environmental Effects of Energy Systems, Brookhaven National Laboratory, United States. Major points were made on various issues.

● Several papers stressed the continuing need to improve databases and analytical tools so that uncertainties in data and results can be reduced. Putting monetary values on health impacts from energy systems is a difficult task and many problems still must be resolved. However, the monetary valuation of impacts can assist in the decision-making process, both in the selection of fuels and technologies and in the location of power plants.

● The standard approach of analyzing direct health effects caused by exposure to physical and chemical agents should be extended to include consideration of psychological effects (e.g. stress, anxiety, fear), Dr. Pop-Jordanova suggested. Her research showed there is a great difference between the real and perceived health effects from energy systems. Objective and transparent information from comparative assessments could help to reduce this difference.

● All energy technologies involve some degree of health risk. Dr. Morris noted that despite many studies on the relative health effects of different methods of generating electricity, the results do not appear to have affected actual investment choices. However, due to the increasing public concern about health and environmental aspects of power generation, it may be expected that such studies would have a greater influence on future decisions. It is thus important that the comparative assessment approaches are capable of providing decision-makers with scientifically correct and understandable information.

● Scientists and analysts still have a long way to go in order to provide the type of comprehensive information that is needed by decision-makers, Prof. Munasinghe stressed in his concluding remarks. More has to be done in investigating comprehensively transboundary and global issues such as greenhouse gas emissions and impacts; assessing long-term effects that might arise from chemical and radioactive waste disposal for example; and exploring all potential impact pathways. The uncertainties that still prevail in data and in results from modelling studies make it impossible to give definitive answers to all questions. Thus, there is a need for more co-operation and exchange between analysts and decision-makers to transfer adequate information and useful results from analytical studies to those responsible for policy making.

Session 3: Integrated Frameworks for Comparative Assessment. Chaired by Mr. Kurt Yeager, Electric Power Research Institute, United States, this session included presentations by Prof. P. Capros of Greece; Mr. N.J. Eyre and Ms. J.E. Berry on the ExternE Project of the EC and the US Department of Energy; Prof. M. Munasinghe of Sri Lanka; Dr. S. Hirschberg of the Paul Scherrer Institute in Switzerland; Dr. Y. Uchiyama, Central Research Institute of the Electric Power Industry, Japan; Dr. I.F. Vladu of the IAEA; Prof. M. Chadwick, Stockholm Environment Institute, Sweden; and Dr. R. Wilson, Harvard University, United States. Selected highlights are featured here.

● The ExternE project has shown that it is difficult to achieve full comparability between different fuel cycles, since each one has unique impacts and the assumptions adopted in the quantification can affect their comparison. Some fuel cycles have very long-term impacts, notably global warming impacts from fossil fuel cycles and the radiological impacts of long-lived isotopes from the nuclear fuel cycle. Both the monetary values and the methodology for weighting the distribution of risks to the population and over time and space remain controversial, which adds to uncertainty. Despite some unresolved issues, the study has made important advances in: evaluating damages over very long time and space scales; reporting them in a consistent manner for different energy cycles; identifying the remaining uncertainties; and highlighting important parameters in the decision-making process.

● A life-cycle analysis of electricity generation chains in Switzerland showed that nuclear power emits some 100 times less greenhouse gases than hard coal chains and 10 times less than solar systems. For fuel cycles other than fossil, the power plant contributes only a minor amount to greenhouse gas emissions, while the other steps of the chain are responsible for the major share of emissions, owing to energy consumption and material production in these steps. In the Swiss context, expected technological improvements will reduce greenhouse gas emissions by some 30% for the coal-fired and nuclear systems; and by a factor of five for solar systems with the introduction of amorphous silicon panels.

● A life-cycle analysis of greenhouse gas emissions from electricity generation and supply systems in Japan found that coal, oil, and gas systems emit respectively some 270, 190, and 180 grams of carbon per kWh of electricity generated. On the other side, hydropower, nuclear power, and solar photovoltaic power emit respectively some 5, 6, and 35 grams of carbon per kWh. Technological improvements are expected to reduce significantly the greenhouse gas emissions from electricity systems. Combined cycle gas turbine plants fuelled with liquefied natural gas (LNG) will emit 140 grams of carbon per kWh as compared to 180 grams per kWh with currently used natural gas fired plants. The progress is expected to be even more significant for nuclear power and photovoltaic systems. Advanced nuclear reactors with a closed fuel cycle will emit some 2 to 3 grams of carbon per kWh (versus 6 grams per kWh with current nuclear technology) and photovoltaic systems using amorphous silicon cells will emit 8 grams of carbon per kWh (versus 35 grams per kWh with photovoltaic power plants now in operation).

● All approaches to environmental risk assessment have difficulties in regard to quantitative estimation; not only are the environmental effects not readily quantified but there is no general agreement on what should be quantified, Prof. Chadwick noted. A number of methods have been proposed in order to overcome this problem and a number of possible approaches have been taken to comparative environmental risk assessment. However, more work needs to be done to reach some level of agreement on the approach which is most useful in the decision-making process, and he recommended that this could be a fruitful area of work for the next phase of the DECADES project.

● Four issues dominate public concerns about energy sources, although the magnitude of the risk of each is controversial, either because the experts do not agree or the public does not trust the experts, in the view of Dr. Wilson. The four are the probability and effect of a severe nuclear power accident; the health impact of particulate air pollution; the global climate effect of increased CO_2 emissions from burning fossil fuels; and wastes from the nuclear fuel cycle. Dr. Wilson stressed that severe accidents can and do happen in energy systems, and that overall nuclear power's safety record is excellent. The effects of fossil fuel use on public health are primarily those of air pollution, especially from emissions of very small particles and sulphates. He noted that many studies show that it seems likely that CO_2 concentrations in the earth's atmosphere will rise to two or three times the historical levels within the next century. Although there remains considerable controversy about what the effects will be, it generally is agreed that we are making a large change in an important climate parameter (CO_2) which could affect the entire earth. Nuclear power, whose CO_2 impact is negligible, has the potential to replace at least a significant share of fossil fuels for electricity generation.

With regard to wastes from energy systems, Dr. Wilson noted that many experts are of the opinion that nuclear power is the only energy system for which society has any idea of a sensible long-term solution. Coal wastes are not perceived by the public as a major problem, yet these wastes contain radioactive materials with half lives comparable to long-lived nuclear wastes. Furthermore, the volume or weight of wastes from coal production and burning dwarfs that from the nuclear fuel cycle. In the United States, for example, about 800 million tons of coal are mined in the country each year, producing some 120 million tons of ashes and 20 million tons of sulphur compounds when it is burned for electricity generation.

Session 4: Implementation of Comparative Assessment. Chaired by Prof. Zhou Dadi of China, this session included presentations by Mr. L. Bennett *et. al.* of the IAEA; Prof. T. Lefevre, Economic and Social Commission for Asia and the Pacific (ESCAP); Mr. T. Herberg and Mr. U. Fritsche, Germany; Mr. M. Amann, International Institute for Applied Systems Analysis (IIASA); Mr. R.. Campo, Colombia; and Dr. C. Heaps *et. al.*, Stockholm Environment Institute (SEI)-Boston Centre, United States.

● Results were reported from some 20 comparative assessment case studies sponsored by the IAEA as part of the DECADES project. The studies sought to identify electricity generation strategies that would meet the objectives of environmental protection, in particular reduction of atmospheric emissions at acceptable cost. Overall results showed that significant reductions of emissions and other environmental burdens can be obtained by improving the efficiency of existing facilities at different levels of the energy chains, including the fuel conversion and transportation steps. The rehabilitation of existing power plants, in particular by adding pollution control technologies, is often a cost-effective measure for mitigating environmental impacts. Improving the overall efficiency of energy systems by promoting co-generation is identified as a very cost-effective option in many countries, especially where heat distribution networks already exist for district heating.

In those studies where it was considered, nuclear power appeared to be cost effective for reducing emissions of SO_2, NO_x and CO_2. For example, some studies showed that, although CO_2 emission reduction targets could be achieved without nuclear power, its use would lead to significantly lower costs. In general, the studies showed that the possibilities for CO_2 emission reduction in the electric power sector would be very limited without the use of nuclear power.

● ESCAP has carried out Energy Environmental Planning (EEP) case studies in the framework of the Programme for Asian Co-operation on Energy and the Environment. Prof. Lefevre stressed that, although sustainable development now is widely embraced as a key societal goal, it is clear that the specification of sustainable policies for the energy sector is a complex task that poses serious dilemmas for many Asian countries. Developing countries of Asia are striving to increase energy production and/or imports to keep up with desired energy consumption. Because the countries are developing rapidly and energy production capacity must be added quickly, emphasis has been placed on minimizing capital costs, with relatively little concern for environmental consequences. However, these countries increasingly are feeling pressure, from multilateral lenders and donor countries, to pay more attention to the environment and to sustainable development. Also, as many of the countries have become more prosperous, their citizens are becoming less willing to sacrifice environmental quality (including public health) for cheap energy. As a consequence, the countries are seeking technical and scientific information, as well as state-of-the-art methodologies and tools for energy-environmental analysis to help them make informed decisions about their energy development strategies.

● Under the SEI/UNEP Fuel Chain Project, two countries (Venezuela and Sri Lanka) have used the project's software and database to examine fuel and technology options across a range of fuels and energy sectors. The two case studies showed that fuel chain analysis can be useful in highlighting trade-offs between local and global environmental impacts. For example in Venezuela, the analysis found that while compressed natural gas (CNG) would be favoured over diesel in terms of local air pollution resulting from the power plant, the use of CNG could result in higher global emissions of greenhouse gases.

Session 5: Implementation of Comparative Assessment: Country Case Studies. Chaired by Dr. Cesar Cordoba-Salazar of Colombia, this session included presentations by Dr. T. Larsson *et. al.*, Sweden; Dr. A. Khan *et. al.*, Pakistan; Dr. A. Popescu *et.al.*, Romania; Dr. A. Das, India; Dr. M. Vielle, France; Dr. J. Geidl and Dr. S. Kanhouwa, United States; and Ms. S. Messner, IIASA in Austria.

● Studies in Sweden have compared the effect on CO_2 emissions from three different policies on energy taxes and subsidies. The main differences were between the tax systems introduced in 1990 and 1994, as well as some difference in the policies on subsidies for the energy sector. The results showed that the 1994 changes in energy policy would lead to CO_2 emissions being reduced in 2005 to 20% below what they would have been if the 1990 policy were still in use. However, beyond 2005, i.e. from the start of the planned nuclear phase-out and beyond, CO_2 emissions will rise drastically regardless of which policy (1990 or 1994) would be in effect.

● In Pakistan, a study carried out under the DECADES project involved two possible paths of development of electricity generation, one that envisaged a reasonable growth in nuclear power capacity and the other postulating a moratorium. The two cases were compared in terms of their associated emissions of pollutants such as SO_2, NO_x, CO_2, methane, radioisotopes, taking into account the full energy chain of each supply option. The study showed that the increased use of nuclear power in Pakistan would not only be cost effective but also would be helpful in reducing environmental impacts from electricity generation in the country.

- In Romania, a comparative assessment of alternative electricity supply strategies showed that the least-cost plan for expansion of the electricity generation system would use combined cycle natural gas-fired power plants. The case with expanded use of nuclear power showed total costs (up to 2015) that were some 2.6% higher than the least-cost plan; however, the use of nuclear power would allow emissions of CO_2 and NO_x to be reduced by 70% and 80%, respectively, up to 2015, relative to the least-cost case.
- In India, a study examined different CO_2-abatement measures, such as accelerated development of hydropower, increased use of renewable energies, and increased use of clean coal technologies. The power sector is the single largest contributor of CO_2 emissions in India, and electricity demand is expected to grow at 6% to 7% per year. If the current domination of coal in electricity generation continues, then CO_2 emissions from the electricity sector would triple by the years 2011-2012. The study showed that the lowest cost strategy involved the accelerated development of hydropower. It would not only lead to lower costs but also would reduce CO_2 emissions in 2011/2012 by some 12%. The study also examined an "abatement scenario" which assumed a 25% reduction of CO_2 emissions up to 2011/2012. This scenario included both the accelerated development of hydro and the introduction of clean coal technologies. Results showed that this scenario would be some 7% more costly than the business-as-usual scenario.
- In France, a study examined nuclear power's economic and environmental impacts. It found that if France had not developed its nuclear power programme, the price of electricity would be some 15% higher than what exists today, and would be highly sensitive to fluctuations in the price of imported coal. Sulphur dioxide emissions would be 18% higher that the current levels, and other atmospheric emissions would be higher by an even greater amount.
- A IIASA research project is examining long-term options and strategies for sustainable energy development, in particular by assessing the potential for reducing energy use and the carbon intensity of energy worldwide. The project has led to an inventory of technologies for reducing CO_2 emissions and the data's application in a number of studies. The database contains information on over 1400 technologies, with more than 70% of the entries being for electricity generation and cogeneration technologies.

Session 6: Comparative Assessment in Decision Making. Chaired by Dr. Nengah Sudja of Indonesia, the final technical session included presentations by Ms. B. Reuber of Canada; Prof. R. Dutkiewicz, South Africa; and Dr. D. Martinsen and Dr. A. Voss *et. al.*, Germany. A number of important points were addressed.

- In Canada, Ontario Hydro has included comparative assessment as an integral part of its decision-making process. Externality values (i.e. social costs, such as health effects, that are not always fully reflected in the price of electricity) have been established for Ontario's fossil-fired power stations and for the full life-cycle of its nuclear power stations. Preliminary data show that for the fossil power stations, the externality values ranged from a low of 0.06 Canadian cents per kWh to a high of 1.66, with an average of 0.40. For nuclear stations, the estimated externality costs ranged from a low of 0.0015 to a high of 0.12 cents per kWh.
- A comprehensive study in Germany analyzed possible paths for the future development of the national energy system, with the objective of identifying strategies for reducing CO_2 emissions by 30% up to the year 2005 and 50% up to the year 2020. The possible role of nuclear power as a mitigation measure was analyzed by four separate 50% CO_2 reduction scenarios, including one with a build-up of nuclear capacity. The study concluded that a 50% CO_2 reduction by the year 2020 is feasible, and that it can be attained with technologies that are already available or known to become available in the next 30 years. The 50% CO_2 reduction target could be achieved without the use of nuclear energy as a carbon-free energy carrier, although at considerable cost. The expanded use of nuclear energy would allow the target to be reached with significantly lower costs of energy supply.

Future directions

The international symposium underscored the importance of comparative assessments in support of decision-making in the electricity sector. It further identified a number of areas where greater global co-operation is needed to improve the base of information and the analytical tools and methodologies for conducting comparative studies.

Through its programmes and activities, the IAEA is continuing to examine areas in which its expertise and support can best be applied to assist national policy- and decision-makers in objectively and comprehensively assessing their energy systems and strategies. ❐

Environmental impact of radioactive releases: Addressing global issues

New information presented at an IAEA symposium is helping the global community to address radioecological concerns

by Gordon Linsley

In the decade after the United Nations Conference on the Human Environment, held in Stockholm in 1972, the IAEA organized a series of international meetings with themes concerned with radionuclides and their behaviour in the environment. In the atmosphere of concern for the environment which followed the UN Conference, the IAEA-sponsored meetings provided a focal point for international discussion and served to summarize the state of knowledge on radionuclide behaviour in different environmental media. A considerable amount of research was, at that time, being directed in IAEA Member States towards achieving an understanding of the behaviour of radionuclides, and especially of long-lived radionuclides, in the terrestrial and aquatic environments. The last symposium in this sequence of meetings was held in Knoxville, Tennessee, in the United States in 1981 with the title, "The Environmental Migration of Long-Lived Radionuclides".

Today, there is a new and increasing concern for the environment stemming from various evidences that the environment is being seriously affected by the activities of human beings. We are all aware of the effects of regional pollution and the possible threats of global warming and ozone layer depletion. It was to address these and other similar concerns that the UN held its Conference on Environment and Development in Rio de Janeiro in 1992. In the context of radionuclides in the environment there has also been a renewed interest; however, the stimulus in this case has come from a different direction. The relaxation of tensions between the countries of the east and the west has allowed much previously classified information on matters related to radioactive releases and their environmental impacts to become available. It is this new source of environmental information, together with the environmental information from the Chernobyl accident, which has renewed interest and stimulated research on radionuclides in the environment in recent years. In many cases, the need to gain greater understanding of radionuclide behaviour in the environment is linked to the plans for cleaning up the environmental contamination which resulted from weapons production operations and the early days of nuclear fuel cycle development.

It was with these developments in mind that the Agency organized the International Symposium on Environmental Impact of Radionuclide Releases, in Vienna in May 1995.* A total of 222 experts from 39 countries and five international organizations participated. This article summarizes the Symposium's highlights in selected topical areas that were addressed.

Studies in the marine environment

Since the time it was revealed that high- and low-level radioactive wastes had been dumped in the shallow waters of the Kara Sea in the Arctic over a period of 30 years, many studies have been initiated to evaluate the implications of the dumping. Shortly after the revelations in late 1991 and 1992, the IAEA, in collaboration with affected countries, launched an international project aimed at assessing the current and possible future impacts on health and the environment of the dumping. This project, known as the International Arctic Seas Assessment Project (IASAP), is still continuing but some preliminary results were reported at the Symposium. Other presentations from Norway and the Russian Federation and from the IAEA's Marine Environment Labo-

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*The Proceedings of the *International Symposium on Environmental Impact of Radioactive Releases*, held in Vienna 8-12 May 1995, have been published by the IAEA. See the "Keep Abreast" section of the *IAEA Bulletin* for ordering information ratory (IAEA-MEL) described the investigatory cruises to the affected area and associated experimental studies. The cruises have succeeded in locating some of the dumped high level wastes and measurements have been made *in situ* and also on samples taken in the vicinity of the dumped objects (submarines, reactor compartments, waste containers). The studies have shown that contamination can be detected close to some of the objects but at distances greater than a few tens of meters little or nothing can be detected. Since the wastes are located in a remote and inhospitable region, it has been concluded that they pose no threat to health or to the environment at the present time. However, there remains concern about the possible hazards which might result from leakage of radionuclides from the wastes at some future time. This issue is being evaluated as part of the IASAP together with an analysis of the feasibility of carrying out remediation actions on the wastes.

The session on the marine environment also contained presentations on the analysis of the impact of the discharges from the Sellafield reprocessing plant in the United Kingdom, a subject which has been controversial in recent years. The presentations focused on the historical development of discharge control at the site. They showed how discharges have been dramatically reduced from the levels in the 1970s and early 1980s by the introduction of effluent clean-up technology. At the same time, methods for analyzing the environmental impact of the discharges have also developed in sophistication and sensitivity.

Environmental model testing

The session on this subject was mainly focused on the IAEA programme called VAMP (Validation of Environmental Model Predictions) which ran from 1988 to 1994. The programme was aimed at taking advantage of the widespread distribution of radionuclides in the environment after the Chernobyl accident. The results of the subsequent measuring and monitoring programmes formed a basis for testing the predictions of mathematical models.

The VAMP programme proved to be very successful and involved well over 100 scientists from many different countries. Several presentations based around the results of the four VAMP working groups (Terrestrial, Urban, Aquatic (Lakes and Rivers and Reservoirs) and Multiple Pathways) were made at the Symposium. The exercises in VAMP provided a unique opportunity for testing the accuracy of model predictions. In some cases, existing models and transfer coefficients were shown to give a reasonable representation of the transfer of radionuclides through the environment. In other cases, previous generic assumptions regarding, for example, dietary intakes and food sources, were shown to be inappropriate for application to a particular environment. A general lesson from the studies is that each environment is different to the extent that it is unlikely that reliable predictions of radionuclide transfer to humans can be made without a detailed knowledge of the characteristics of the environment and of the habits of the exposed population group. In the model testing studies, there was a general trend towards over-prediction. One of the most likely reasons for this is associated with the use to which models are normally put, that is, they are most commonly used for the purpose of comparing radiation doses received by critical population groups from releases of radionuclides from operating practices with dose limits. In this application, there is a need to be sure that doses do not exceed the dose limit and so the assumptions and parameter values in the models tend to be selected in a way which will make underestimation unlikely.

Another feature of the VAMP programme, illustrated by presentations at the Symposium, was the opportunity for reviewing the state-of-the-art in modelling important transfer processes. Expert reviews carried out in the course of the VAMP programme have resulted in IAEA publications on the modelling of the resuspension process (ground to air), the interception and retention of radionuclides on plant surfaces, transfer in natural ecosystems, and the effectiveness of food preparation methods for the removal of radionuclide contaminants.

Radiation dose reconstruction

Operations in the early years of nuclear weapons development were directed at production targets and so the proper management of radioactive and other wastes was not usually given a high priority. Operational releases of radionuclides to the atmosphere occurred at high levels from several of the nuclear weapons production facilities. There were also releases to the environment from accidents at some of the facilities and also as a result of nuclear weapons testing. Information on these events has become available in recent years as previously classified documents have been released for public scrutiny.

The concern of potentially affected population groups and, in some cases, the legal action taken against the responsible authorities, has

Annual Dose from Natural Radiation Sources in the Environment (in areas of normal background radiation)

Source	Annual effective dose (micro-sievert) External	Internal	Total
Cosmic rays	380		380
Cosmogenic radionuclides		12	12
Terrestial radionuclides			
Potassium-40	130	170	300
Uranium-238 series:			
$^{238}U \rightarrow {}^{234}U \rightarrow$ Thorium-230	140	1	
Radium-226		4	1400
Radon-222 → Polonium-214		1200	
Lead-210 → Polonium-210		50	
Thorium-232 series	190	80	270
Total (rounded)	**840**	**1520**	**2400**

Long Term Committed Doses from Man-Made Sources

Source	Main radionuclides	Collective effective dose (man-Sv)
Atmospheric nuclear testing	Carbon-14, Caesium-137, Strontium-90, Zirconium-95	30 000 000
Chernobyl accident	Caesium-137, Caesium-134, Iodine-131	600 000
Nuclear power production	Carbon-14, Radon-222	400 000
Radioisotope production and use	Carbon-14	80 000
Nuclear weapons fabrication	Caesium-137, Ruthenium-106, Zirconium-95	60 000
Kyshtym accident	Cerium-144, Zirconium-95, Strontium-90	2 500
Satellite re-entries	Plutonium-238, Plutonium-239, Caesium-137	2 100
Windscale accident	Iodine-131, Polonium-210, Caesium-137	2 000
Other accidents	Caesium-137, Xenon-133, Cobalt-60, Iridium-192	300
Underground nuclear testing	Iodine-131	200

Most significant releases of radionuclides to the environment from human activities have been from atmospheric nuclear weapons testing. Next in importance is the Chernobyl accident, followed by long-term exposures from carbon-14 and radon-222 associated with nuclear power production. A large part (86%) of the collective dose from nuclear weapons testing is due to long-term exposure from carbon-14. Some perspective on these estimated doses from human activities can be gained by comparison with those from natural sources. An estimated 13,000,000 man-sievert due to natural sources (e.g., cosmic rays, potassium-40 in the body, and radon gas) is delivered each year to the world population (2400 micro-sievert x 5.4 x 10^9 persons).

prompted investigations of the radiation exposures received by local populations as a result of the releases. At the Symposium, presentations on "dose reconstruction" themes were made in connection with the 1957 Khyshtym accident (Russian Federation) and with nuclear weapons testing at Semipalatinsk (Kazakhstan), and the Nevada Test Site (United States). The long time periods which have elapsed since the releases occurred have created problems for radiological assessment "detectives" to solve, and, for example, it has necessitated the development of new environmental techniques for estimating the doses received by exposed populations up to 40 years ago.

Environmental remediation

The historical problems discussed above have also created a legacy of environmental contamination in many parts of the world. In addition to the contamination of parts of the terrestrial and aquatic environments created by weapons production and testing activities, many countries are affected by the residues from uranium and thorium mining operations, and from other non-nuclear related mining activities. Contamination from the Chernobyl accident still affects some countries, especially in forested and upland areas. Research into cost-effective and environmentally friendly solutions to these problems is going on in many countries. Presentations at the Symposium included descriptions of ameliorative techniques to be applied to soils, water, vegetation and cattle.

Topical discussion sessions

Discussion sessions were held on two topics which are currently subjects of controversy and debate within the radioecological community.

Environmental Protection. The generally accepted position on this subject is that if human beings living in the environment are adequately protected from ionizing radiations then it can be assumed that other living species are also adequately protected at the population level although not necessarily at the individual level. This is the view currently taken by the International Commission on Radiation Protection (ICRP) and the position has been supported by an IAEA study published in 1992.*

However, circumstances can be envisaged in which this assumption, on its own, may be insufficient to guarantee protection of non-human species, for example, where radionuclides are released to an area where no humans are present. There could also be presentational reasons for wishing to have specific criteria for protecting environmental species; the accepted ICRP approach might be misunderstood and interpreted as an attitude of unconcern for the environment. Explicit criteria for protecting non-human species might, therefore, be justified on these grounds. On the other hand, the introduction of specific environmental protection criteria could carry with it the requirement for more environmental monitoring and assessment than is currently practiced and, overall, it could involve substantial extra costs for utilities and regulators. These are some of the points debated during the session on environmental protection and it is clear that more discussions on the subject will take place over the next few years.

The Precautionary Principle. The principle of precautionary action has appeared in various international documents in recent years, notably in UNCED's Rio Declaration (Agenda 21)and in some regional conventions on protection of the marine environment. It is stated in various different ways; one example, taken from the Convention on the Protection of the Marine Environment of the Baltic Sea is as follows: "to take preventive measures when there is reason to assume that substances or energy introduced, directly or indirectly, into the marine environment may create hazards to human health, harm living resources and marine ecosystems, damage amenities or interfere with other legitimate uses of the sea even when there is no conclusive evidence of a causal relationship between inputs and their alleged effects".

The final part of the definition is obviously controversial and it was the focal point of the discussion session on the precautionary principle at the Symposium. On the one hand, it can be argued that most present legislation on waste discharge can be seen as unsatisfactory in that it requires scientists to prove that there is an effect from a harmful substance in the environment before regulatory measures will be introduced. The precautionary approach would require a "reversal of the burden of proof". Such a development could be useful in cases where little is known about the substance that is planned to be discharged or where the biogeochemical cycle and risks of the substance in the environment are poorly understood. On the other hand, the precautionary principle, if taken literally, could imply that no discharges of substances to the environment should be allowed since it is likely to be impossible to provide absolute proof that no harm will occur.

It is clear that while the precautionary approach is appropriate as a general concept, it needs to be interpreted for application to particular situations. It should be applied in ways which do not prevent the controlled release of substances to the environment whose properties are well known and whose behaviour in the environment to which they are being released is well understood. ❐

* *Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards*, IAEA Technical Reports Series No. 332, Vienna (1992).

International Centre for Theoretical Physics: A new institutional framework

Under a new Tripartite Agreement, the IAEA, UNESCO, and Italy strengthen their co-operative support of the research centre

by Edwin Nwogugu

Over more than three decades, the International Centre for Theoretical Physics (ICTP) in Trieste, Italy, has blossomed through the vision and energy of its creator, Professor Abdus Salam, and his collaborators into a leading international centre for research and training. Initially, the Centre's activities were mainly in the areas of nuclear physics and nuclear data, high energy physics, atomic physics, fusion physics and mathematics. Over time, they extended to broad areas of physics related to energy, solid state physics, environment, medicine, biology, space science, lasers and mathematics, including computer science in its various aspects.

Today, under the stewardship of its new Director, Prof. Miguel Angel Virasoro, the Centre continues to play a unique role as a forum for the training of scientists from the Third World and as a point of contact for the exchange of scientific expertise between industrialized and developing countries. Thousands of scientists study at the ICTP each year, participating in workshops, seminars, training courses, and a range of other scientific activities.

A number of important changes were recently made to the organizational framework of the ICTP. These took effect 1 January 1996, when a Tripartite Agreement between the IAEA, the United Nations Scientific, Cultural and Educational Organization (UNESCO), and the Italian Government came into force. On the same date, a new Joint Operation Agreement between the Agency and UNESCO also took effect. These steps transfer the administrative responsibility for the ICTP from the IAEA to UNESCO. This article reviews the background and the changes to the organizational framework of the Centre which were brought about by the two new agreements.

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Historical legal background

The IAEA's support of the ICTP goes back more than 30 years. In 1963, the Agency's Board of Governors, acting on the recommendation of the General Conference, decided to establish at Trieste an international centre for theoretical physics on a provisional basis under IAEA auspices. Thereafter, the Agency negotiated an agreement with the Italian Government — the Agreement between the Agency and the Government of Italy Concerning the Establishment of an International Centre for Theoretical Physics at Trieste (INFCIRC/51) — which was approved by the Board in September 1963. This Agreement was to remain in force for 4 years subject to extension by mutual agreement of the parties.

Four years later, in 1967, the parties decided not to renew the earlier agreement but to conclude in its place a new one — the Agreement between the Agency and the Government of Italy Concerning the Seat of the International Centre for Theoretical Physics (INFCIRC/114) — hereinafter referred to as "the Seat Agreement". It dealt with five principal questions concerning the Centre: the seat of the Centre; provision of public services; privileges and immunities of the Agency at the Centre; liaison with the government; and settlement of disputes.

At the same time, the Agency left open the question of the participation of other interested international organizations in the running of the Centre. In 1969, the Agreement between the IAEA and UNESCO Concerning the Joint Operation of the International Centre for Theoretical Physics at Trieste (INFCIRC/132), hereinafter referred to as "Joint Operation Agreement" was concluded. Article 1 sets out the purpose of the Centre, which is to foster, through training and research, the progress of all branches of theoretical physics in accordance with the IAEA Statute and the UNESCO Constitution. The Centre's functions were the training of young physicists for research, especially from developing countries; help in fostering the growth of advanced studies of theoretical physics, especially in developing countries; conduct of original research; and the provision of an international forum for personal contacts between theoretical physicists from countries in all stages of development.

The Centre's administration was to be carried out by the Agency on behalf of both organizations. As a result, the ICTP's Director and staff were IAEA personnel. However, decisions on the appointment, promotion, and termination of the Centre's professional staff were to be taken jointly by the IAEA and UNESCO.

The Agreement also established a Scientific Council, jointly selected and appointed by the Directors General of the IAEA and UNESCO. The Council's terms of reference *inter alia* are the provision of advice to the Directors General of both organizations on the training, research, and other programmes of the Centre; the appointment of the Director and the staff needed to carry out the ICTP's programmes; and the institutes of theoretical physics in developing countries which will be affiliated to or enter into federation agreements with the Centre. The Council also evaluates the Centre's activities and reports thereon to the Directors General of both organizations.

On financial matters, the Agreement provided for both organizations to contribute to the Centre's budget, which would form part of the Agency's budget.

Changes in the ICTP's administration

Changes in the arrangements for the administration of the Centre were influenced by a number of factors. First, over the years, the Centre had expanded its activities considerably to include areas which were not related to the peaceful uses of atomic energy. It was therefore doubtful whether it could continue as a part of the Agency, while executing activities which were beyond the IAEA's mandate. Secondly, the ICTP's activities could fit more appropriately within the wide scientific mandate of UNESCO. Thirdly, the view was expressed that in consideration of Italy's role as the host and the highest contributor to the Centre, it should be given a more active role in the Centre's administration. Lastly, UNESCO had indicated its willingness, as a joint operator, to take over the administrative responsibility for the Centre.

In 1992, the IAEA Director General was mandated by the Board to transfer the ICTP's administrative responsibilities to UNESCO and to negotiate an agreement in that respect. Tripartite negotiations took place over several months between the Agency, UNESCO, and the Italian Government. The talks resulted in the conclusion of two agreements. The first — Agreement between the IAEA, UNESCO, and the Government of the Republic of Italy concerning the International Centre for Theoretical Physics at Trieste (INFCIRC/418) — hereinafter referred to as the "Tripartite Agreement", laid down a new framework for the Centre's administration. The Joint Operations Agreement was replaced by a new and modified agreement of the same title (INFCIRC/499).

The Centre's President. As the Centre's activities grew, it became necessary to assign new responsibilities to the founding Director, Professor Salam, in recognition of his immense contributions. The IAEA and UNESCO as joint operators of the Centre and the Italian Government as the host state and major donor offered Professor Salam the position of the President of the Centre which he took on 1 January 1994. The functions of the President include, *inter alia,* the setting up of a forum for the co-ordination of programmes of activities of the international scientific institutions in the area of Trieste.

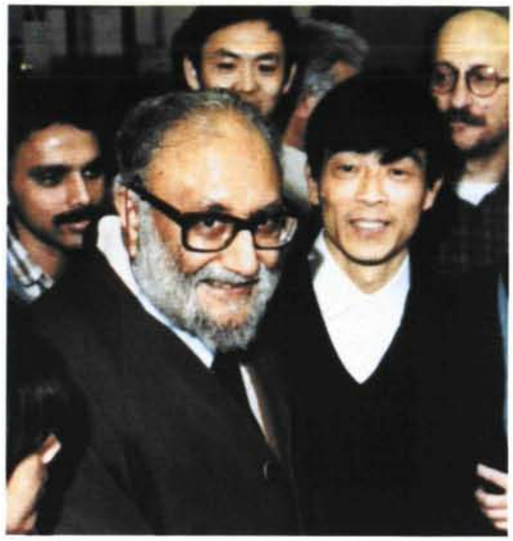
Tripartite Agreement

The Tripartite Agreement which entered into force 1 January 1996 contains a number of important provisions.

Seat Agreement. Article 1 amends the Seat Agreement to provide the framework for the transfer of the administrative responsibility from the Agency to UNESCO. UNESCO replaced the Agency as a party to, and took over all rights and obligations of the Agency, under the existing Seat Agreement on the understanding that the relevant provisions on the Agreement of the Privileges and Immunities of the Agency continues to be applicable *mutatis mutandis* with regard to the Centre after its transfer to UNESCO. Consequently, the words "the Agency" are replaced as appropriate with "UNESCO" in the existing Seat Agreement.

The Organization of the Centre. Article 2 establishes that the organizational framework of the Centre consists of the following: the Steering Committee; the Director; and the Scientific Council.

The Steering Committee. A Steering Committee was created by Article 3 as an apex authority for the Centre. An innovation in the organization of the Centre, it is to be composed of the following members: one high-level representative each designated by the Director General of UNESCO, the Director General of the Agency; and by the Italian Government; such



Prof. Miguel Angel Virasoro, new ICTP Director, with Directors General Blix of the IAEA *(left)* **and Mayor of UNESCO** *(right)*. *Above right:* **Prof. Abdus Salam, founder and now President of the ICTP.** *(Credit: ICTP)*

other members as may be appointed by the Steering Committee in order to ensure appropriate representation of those countries or institutions having made particularly important contributions to or having a particular interest in the activities of the Centre; and the Director who is also the *ex officio* Chairperson of the Steering Committee.

The representatives of the two organizations and the Italian Government may be accompanied by experts to meetings of the Steering Committee. In addition, the Chairperson of the Scientific Council may attend meetings of the Steering Committee in an advisory capacity.

Article 4 sets out the functions of the Steering Committee, which are: to formulate the general guidelines for the Centre's activities, taking into account its objectives as specified in the joint Operation Agreement; subject to the budgetary appropriation by the respective competent organs, to determine the annual level of the budget, the level of respective contributions, the financial plans, and how the funds available for the operation of the Centre are to be used; to consider the proposals of the Director for the programme, work plans, financial plans, and budget proposals of the Centre and to take decisions thereon; to consider the annual and other reports of the Director on the activities of the Centre; to submit a report on the Centre's activities to UNESCO and the Agency; and to recommend to the Director General of UNESCO the names of candidates for the post of the Director of the Centre.

The Director. Article 5 provides for the appointment of the Director of the Centre by the Director General of UNESCO in consultation with the IAEA Director General and the Italian Government from candidates recommended by the Steering Committee. The Director shall hold office for a term of 5 years renewable and is the Centre's Chief Academic and Administrative Officer. He or she is empowered to administer the Centre; prepare proposals for the Centre's general activities and work plans taking into account the advice of the Scientific Council for submission to the Steering Committee for its approval; prepare the financial plans and budget proposals of the Centre for submission to the Steering Committee for its approval; execute the ICTP's work programmes and make payments within the framework of general guidelines and specific decisions adopted by the Steering Committee in accordance with Article 4. Besides the above enumeration, the Director has such other functions and powers as may be prescribed by the Agreement pertaining to the structure of the Centre or as may be conferred on him or her by the Director General of UNESCO.

The Scientific Council. A new Scientific Council was created under Article 6 on a broad geographical basis composed of up to 12 distinguished specialists in disciplines relevant to the Centre's activities. The members sit in their personal capacity. The Council Chairperson is appointed jointly by the Directors General of UNESCO and the IAEA, after consultations with the Steering Committee and the ICTP Director. The appointment is for a term of 4 years and he or she is eligible for re-appointment. The Council's remaining members are appointed by the ICTP Director after consultations with the Council Chairperson and serve for a term of 4 years. Additionally, UNESCO, the IAEA, and the Italian Government may send specialists in scientific programmes to attend Scientific Council meetings .

The Council's functions are to advise the Centre on programmes of activity, having due regard to relevant global academic, scientific, and educational trends . The Steering Committee and the Director may request the Council's advice on specific issues.

Financial Commitments. To strengthen the Centre's financial base, UNESCO, the Agency, and the Italian Government agreed to contribute to the Centre's budget. The level of contributions of UNESCO and the Agency (subject to budgetary appropriations approved by their competent organs) shall not be lower than that agreed in the exchange of letters dated 11 December 1990, augmented by the respective inflation factor employed by each organization in the calculation of its budget. The Italian Government is to maintain its financial contribution to the Centre at a level not lower than that specified in the same Exchange of Letters or any higher contribution decided upon by the Steering Committee pursuant to Article 4(a). (The Exchange of Letters terminated on the date the Tripartite Agreement entered into force.) As of 1991, the IAEA contributed just over US $1.3 million, UNESCO just over $331,000, and the Italian Government 20 billion Lire annually to the Centre's budget.

Funds allocated for the Centre's operation are paid into a special account set up by the Director General of UNESCO in accordance with the relevant provisions of that organization's financial regulations. The special account is operated and the Centre's budget administered in accordance with the same regulations.

Transfer Of Assets And Liabilities. Under Article 10, UNESCO shall take over in accordance with arrangements to be made between the two parties from the Agency all assets including property and liability pertaining to the Centre.

Article 11 provides for the transfer to UNESCO of Agency staff members posted at the Centre. The transfer is to be effected by agreement between the two organizations taking into account the provisions of the Tripartite Agreement and the new Joint Operation Agreement. All matters not expressly agreed upon by the Parties are to be dealt with in accordance with the relevant provisions of the Inter-Organization Agreement Concerning Transfer, Secondment or Loan of Staff among the Organizations applying the United Nations Common System of Salaries and Allowances. It was underlined in the Article that the transfer itself should not adversely affect the conditions of employment of the said staff members posted at the Centre, including the duration of their contracts and fringe benefits, subject to the availability of the funds for the operation of the Centre. Agency staff members transferred to UNESCO pursuant to this provision shall become staff members of UNESCO.

The transfer to UNESCO of Agency staff posted to the Centre was perhaps the most intricate exercise. UNESCO offered the affected staff new contracts. These staff will continue to enjoy the same conditions in respect of duration of contracts, promotion, and recruitment policy as existed before the transfer. The modalities for the transfer of staff, assets, and liabilities of the Centre to UNESCO were embodied in a Memorandum of Understanding concerning the Transfer of the Administrative Responsibility for ICTP from the IAEA to UNESCO. This document was signed in Trieste by the Directors General of both organizations at the formal transfer of the Centre on 11 January 1996.

Joint Operation Agreement. In view of the changes in the Centre's organizational framework, Article 12 of the Tripartite Agreement provided for amendments to the Joint Operation Agreement. A new Agreement was prepared to replace the old one. In it, the purpose of the Centre was amended by providing that it will foster, through training and research, progress in physics, particularly theoretical physics, in accordance with the constitution of UNESCO and the IAEA Statute. The provisions on the Centre's functions, its staff, and details of collaboration remain the same as in the old agreement. The new Joint Operation Agreement came into force on the same date as the Tripartite Agreement.

Renewed support for the ICTP

The transfer of the Centre's administrative responsibility from the IAEA to UNESCO does not mean the termination of the Agency's interests and participation in its activities. In accordance with the provisions of the Tripartite Agreement, the Agency will continue to play an important role in the operation of the Centre, including contributions to its budget and the determination of the programmes of activity.

A difference can, however, be discerned between the IAEA's approach to the administration of the Centre and that adopted by UNESCO. Before the transfer, the Centre was administered as a unit of the Agency's Secretariat and therefore enjoyed full administrative support services from headquarters. UNESCO, on the other hand, has granted the Centre a large measure of autonomy pursuant to which the Centre will cater for itself in terms of administrative support.

It is hoped that the ICTP's new institutional arrangement will invigorate activities and strengthen the co-operation of the IAEA, UNESCO, and the Italian Government in supporting the Centre's activities. ❐

IAEA Board of Governors' meetings

At its meetings in March 1996, the IAEA Board of Governors continued its discussion of the second part of proposed measures for strengthening the effectiveness and improving the efficiency of safeguards. It further considered reports by IAEA Director General Hans Blix on the implementation of safeguards in the Democratic People's Republic of Korea (DPRK) and on the implementation of UN Security Council resolutions relating to nuclear inspections in Iraq. Other matters before the Board included items related to nuclear safety.

Safeguards Development Programme. The Board resumed its consideration of the second part of proposed measures for strengthening the IAEA's safeguards system. The proposals under discussion (Part 2 measures) are those requiring complementary legal authority. The Board commended the Agency for responding positively to several concerns that had been previously raised by some Member States. While it raised a number of points about certain of the Part 2 measures, the Board emphasized the need to maintain the present momentum and encouraged Member States to co-operate in the interests of finalizing the measures.

In his statement to the Board, Dr. Blix noted the Agency's efforts over recent months in consultation with Member States towards finalizing the proposed measures. He said that considerable progress had been made towards achieving consensus on Part 2 measures, and that the IAEA is continuing to make progress on the implementation of Part 1 measures, which the Board already has approved. Concerning these measures, he said that consultations with States have been initiated to discuss the implementation of specific measures, such as increased co-operation, no-notice inspections, and the collection of environmental samples. He further noted that the Agency's newly inaugurated Clean Laboratory for safeguards analysis at Seibersdorf will soon be in full operation and able to receive and process samples.

Other Safeguards Items. The Board authorized the conclusion of comprehensive safeguards agreements with Algeria and Monaco pursuant to obligations under the Treaty on the Non-Proliferation of Nuclear Weapons *(see related items, page 49)*.

Safeguards in the DPRK. Dr. Blix informed the Board that only limited progress had resulted from technical discussions that took place in the DPRK in late January 1996, and that a further round of technical talks is being scheduled. An important issue to be resolved concerns the preservation of information required for the Agency to verify the correctness and completeness of the DPRK's initial declaration of its nuclear material subject to safeguards. The issue of monitoring of nuclear waste also remains to be resolved, he said. While the DPRK's full co-operation has not been forthcoming, Dr. Blix said that the Agency has been able to resume ad-hoc and routine inspections at facilities not subject to the freeze of the DPRK's nuclear programme foreseen in the US/DPRK Agreed Framework, and that it has received relevant accounting reports for these facilities.

In expressing its support of the Agency's efforts, the Board renewed its call for the DPRK to co-operate fully with the IAEA; reaffirmed that the safeguards agreement is still in force and binding on the DPRK; and particularly emphasized the need to preserve intact all relevant information required in order to verify the correctness and completeness of the DPRK's initial declaration.

Nuclear Inspections in Iraq. The Board received a report on IAEA implementation of nuclear verification activities in Iraq under terms of UN Security Council resolutions. A major component of current work relates to assessing the documentation that was provided to the IAEA in 1995 following the departure from Iraq of a high-level Iraqi official and to following up leads from that documentation. The work is proceeding in parallel with ongoing monitoring and verification activities. In his statement to the Board, Dr. Blix pointed out the continuing challenge of the Agency's work, particularly citing recent developments in Iraq and the problems encountered by inspectors of the UN Special Commission *(see item, page 50)*.

Nuclear Safety. A number of matters were considered. The Board approved the revised *Code on Quality Assurance for Safety in Nuclear Power Plants and Other Nuclear Installations* for publication as a Safety Standards document of the Agency. The Code sets out requirements for establishing and implementing a quality assurance programme, and for its assessment The Board also commented upon the Overview of the IAEA's *Nuclear Safety Review,* which is issued annually as part of the *IAEA Yearbook* The *Review* discusses elements of the global nuclear safety culture, notably legally binding international agreements, non-binding safety standards, and review and advisory services It also focuses on the importance of information-sharing from intergovernmental safety conferences and other meetings, and examines topical safety issues of particular relevance to the Agency's activities and the global community

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International Chernobyl Conference & RBMK Safety Forum

Ten years after the tragic Chernobyl accident, the IAEA, European Commission, and World Health Organization convened an international conference in Vienna that summed up the accident's consequences More than 700 governmental delegates attended the conference from 8-12 April 1996, examining the scientific, medical, psychological, socio-economic, environmental, and political issues involved in assessing Chernobyl's impact

The Conference was chaired by Dr. Angela Merkel, Minister of Environment in Germany During various sessions, experts reviewed the findings of work done to date, including the outcome of two major international conferences, one hosted in November 1995 by WHO and the another in March 1996 under EC auspices in Minsk. Keynote presentations additionally were made by representatives from the United Nations Scientific, Educational and Cultural Organization (UNESCO), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the UN Food and Agriculture Organization (FAO), the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development, and on the results of major projects in Belarus, Russian Federation, and Ukraine. Technical sessions particularly focused on social, health, and environmental consequences. Topics included clinically observed heath effects; thyroid effects; psychological effects; the social, economic, institutional and political impact; and nuclear safety remedial measures A panel discussion further explored the public's perception of the Chernobyl accident.

Proceedings of the Conference are being published by the IAEA

Forum on the Safety of RBMK Reactors. Preceding the Conference, from 1-3 April, the IAEA and UN Department of Humanitarian Affairs (UNDHA) organized an international forum on the safety of Chernobyl-type (RBMK) reactors. Today 15 RBMK units are producing electricity in three States: 11 in Russia, two in Ukraine, and two in Lithuania. The forum examined remedial measures and actions taken since the Chernobyl accident to improve the safety of the reactors. It also addressed questions concerning the containment structure of the protective building around the destroyed Chernobyl-4 reactor (the sarcophagus).

Over the past decade, a considerable amount of work has been carried out by Russian designers and operators to improve RBMK safety and to eliminate the causes that led to the Chernobyl accident. As a result, major design and operational modifications have been implemented However, safety concerns remain, particularly regarding the older, or "first-generation", units

In addition to these actions, the IAEA initiated in 1992 a safety programme for RBMKs with the aim of consolidating results of various national, bilateral, and multilateral activities and to establish international consensus on required safety improvements and related priorities. Through this programme, international assistance is provided to both regulatory and operating organizations involved in technical and financial decisions. The IAEA's activities are co-ordinated with those of an international consortium on the "Safety of Design Solutions and Operation of Nuclear Power Plants with RBMK Reactors" established under auspices of the European Commission

The IAEA has prepared a consolidated list of design and operational safety issues for RBMKs The list suggests safety upgradings in a number of areas: core design and core monitoring, instrumentation and control, pressure boundary integrity; incident and accident analysis, safety and support systems, fire protection, and operational safety

At the Safety Forum, sessions addressed the causes of the Chernobyl accident; remedial actions; national, bilateral and multilateral safety improvement programme; and the sarcophagus. Reports also were made on the current status and safety improvements of the Chernobyl, Ignalina, Kursk, Leningrad, and Smolensk RBMK reactors.

Mururoa Radiological Study

Dr. de Planque, chairwoman of the IAC.

A four-member IAEA technical team completed a reconnaissance mission in March 1996 to the Mururoa and Fangataufa atolls in French Polynesia to help lay the groundwork for a study on the radiological situation there. Among its work, the team checked equipment and facilities for future measurement and sampling campaigns. It also surveyed the lagoon's marine environment, and the soil, bedrock, vegetation, and biota in the terrestrial strips of the atolls.

Requested by the French authorities, the study covers the current radiological situation at the atolls and an evaluation of the long-term radiological situation. The French authorities have agreed to provide the IAEA with information and data required for performing the study. In addition, the study involves the taking of terrestrial and marine samples, work which is scheduled over the next several months. Analysis of the collected samples will be done by the IAEA's laboratories in Seibersdorf, Austria, and in Monaco, as well as by a network of laboratories worldwide. The study, funded through a voluntary contribution from France of US $1.8 million, is expected to take approximately 18 months.

In April 1996, members of the study's International Advisory Committee (IAC) were scheduled to hold their first meeting at IAEA headquarters in Vienna. The IAC was established by IAEA Director General Hans Blix and is chaired by Dr. Gail de Planque, a radiation specialist and former member of the United States Nuclear Regulatory Commission. Other members include experts from Argentina, Australia, Germany, Indonesia, Japan, New Zealand, the Russian Federation, Sweden, the United Kingdom, and the United States. There are also two *ex officio* experts selected by intergovernmental bodies — the South Pacific Forum, the United Nations Scientific Committee on the Effects of Atomic Radiation, the World Health Organization, and the European Commission. The IAC is supported in its work by two task groups and five working groups with a total of about 50 experts. Project management and co-ordination are being undertaken by the IAEA.

Hydrology Workshop for West Asian Region

A group of hydrologists, geologists, and geochemists from water-scarce regions of West Asia recently participated in an IAEA workshop focusing on the methodology of modelling groundwater systems. The workshop was organized by the IAEA's Isotope Hydrology Section within the framework of a regional technical co-operation project. Scientists from Iran, Jordan, Kazakhstan, Kuwait, Lebanon, Syria, Turkey, and Yemen attended the workshop. Training was provided by experts from the United States Geological Survey, which has developed numerical modelling methods and relevant computer codes.

Assessments of the availability and quality of groundwater resources increasingly apply the tools of computer technology. The workshop is among Agency activities that seek to accelerate the application of software for modelling groundwater systems for quantitative evaluation of isotope and chemical data. The training provided hands-on experience in applying computer codes developed primarily to understand the dynamics of groundwater flow. The tools also are useful for predicting the condition of groundwater systems at certain time periods, and the transport of pollutants. Future training courses are expected to be organized in association with participating countries in the IAEA's regional technical co-operation project. They are expected to assist institutes responsible for water resources in improving their quantitative understanding of aquifers and to develop predictive models of pollutant transport, thereby fostering better water management strategies and policies.

Uranium Market Trends

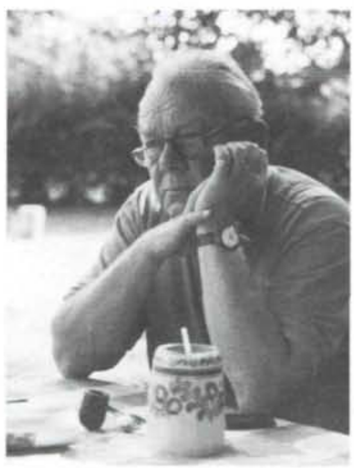
Given recent market trends in the price and inventories of uranium, world uranium production will have to increase significantly from current levels to meet future reactor requirements. As foreseen by the IAEA in the early 1990s, both the price and production of uranium have recovered dramatically over recent years following a lengthy market decline. Since October 1994, the spot price of uranium that most utilities must pay increased 33% by January 1996, and by another 40% by March 1996. The spot price of uranium produced in the Commonwealth of Independent States (CIS) has also more than doubled since October 1994.

Before the increase, uranium spot prices had been declining in the 1990s because of low-priced uranium sales of excess inventories and supplies from the CIS. Consequently, since 1990, world production has been below reactor requirements, as the cumulative drawdown of world uranium inventories reached about 113,000 tonnes uranium. Annual inventory drawdowns during 1993 and 1994 supplied about 45% of the world's reactor requirements. In 1996, the total production shortfall is estimated to be about 25,000 tonnes uranium.

While recent upward price trends have brightened the picture, the imbalance between production and demand remains, and projections are that more uranium will have to be produced to stabilize the market. Starting around the turn of the century, part of the supply is expected to come from uranium fuel made from highly enriched uranium recovered from nuclear warheads. This fuel will probably enter the market at a rate that meets less than 10% of annual world requirements through 2010. Reprocessed uranium may meet another 5%. This leaves about 85% of the reactor requirements through 2010 that will have to be met from new production. As a result, world uranium production will have to increase by about 70% from current levels.

It is unclear whether this level of production can be met. While there are ample known uranium resources to supply reactor requirements well into the next century, the long depressed uranium market has caused a severe shortage of mines and mills. Developing new facilities will take time, as well as a large investment. Currently the market price of uranium is moving up to a level at which such investments would become attractive and restore a balance between uranium production and demand. More information may be obtained from the IAEA Division of Nuclear Fuel Cycle and Waste Management.

In Memoriam: Robert H. A. Skjöldebrand



The untimely death of the IAEA's Robert Skjöldebrand in February 1996 deeply saddened the international community that he so richly served for more than three decades. Mr. Skjöldebrand passed away peacefully and in dignity while visiting in Wollongong, Australia, surrounded by those he loved.

Born in Helsingborg, Sweden, in 1930, Mr. Skjöldebrand retired from the IAEA in 1990 following nearly 30 years of service to the Agency in various capacities. His assignments included serving as Special Assistant to two Directors General: Dr. Eklund, from 1967-68 and Dr. Blix, from 1987 until August 1990. He ably headed sections in both the IAEA Department of Safeguards and the IAEA Department of Nuclear Energy and Safety. A frequent contributor to the *IAEA Bulletin* and other publications, Mr. Skjöldebrand was a talented writer with a bias for facts and a skill for presenting them in clear and understandable terms. He was an editor's best friend: thoroughly professional, thoughtful, and always on time. Not long before his death, he had mused about an article he wanted to write for the *Bulletin* on environmental and energy issues. As usual, he was on the search for facts and sources to update his storehouse of knowledge...his intention, as always, was to write an excellent piece, not just a good one. The words, no less than the man, will be sorely missed.—*The Editor*.

Canada & Sweden: Safeguards Support

An ultraviolet-sensitive telephone lens for the Cerenkov Viewing Device (CVD) has been developed for IAEA safeguards through the Swedish and Canadian Safeguards Support Programmes. The lens will improve the unintrusive verification of light-water reactor fuel by providing a larger image and more detailed Cerenkov characteristics. The lens has advanced light-gathering capabilities and high resolution, thus enabling more effective verification of fuel having a long cooling time and low burnup. The CVD is a Canadian-developed instrument routinely used by safeguards inspectors. The hand-held device provides inspectors with an image displaying the ultraviolet light resulting from the Cerenkov effect that occurs when spent fuel is submerged in water. Inspectors are trained to search for specific light patterns during their verification of the fuel.

The new 250-mm lens was developed at the IAEA's request to meet demanding verification requirements. While the standard CVD lens works well for fuel from pressurized-water reactors, the Cerenkov characteristics of a particular fuel assembly from boiling-water reactors or WWERs are more difficult to distinguish and required an advanced lens. When fitted with the new telephoto lens, the CVD provides inspectors with a much larger image of the spent fuel and more Cerenkov characteristics upon which to base conclusions.

Laboratory and field testing has confirmed the improved performance of the new lens. Field testing of the prototype has been done in Finland and Sweden with the assistance of the Finnish Safeguards Support Programme. The Agency has placed an order for the new lenses that inspectors would begin using for verification of spent fuel. On 22 March 1996, a prototype lens was presented to Mr. Bruno Pellaud, IAEA Deputy Director General for Safeguards, by co-ordinators of the Canadian and Swedish Safeguards Support Programmes.

Ms. A. Nilsson, Sweden, and Mr. R. Keeffe, Canada, present the new lens to Mr. Pellaud (centre).

Poland: Nuclear Seminar

Safety and economic features of advanced nuclear power plants will be presented at an international seminar in Warsaw 25-27 September 1996. Participating will be representatives from the world's leading nuclear plant suppliers and governmental experts involved in decisions about Poland's energy future. Entitled "New Generation Nuclear Power Plants '96", the seminar is being organized by the Polish Nuclear Society and the Association of Polish Electrical Engineers under the patronage of the Ministry of Industry and Trade, National Atomic Energy Agency, and the Polish Power Grid Company. Co-sponsors of the meeting, which is being convened in co-operation with the IAEA, include the European Nuclear Society, Convention of National Societies of Electrical Engineers of Europe, the American Nuclear Society, and the IEE Power Engineering Society.

The seminar is intended to update participants about the types of new nuclear plants that are being developed, and to provide status reports on their safety features and related regulatory matters. Additionally, papers will be presented on technical aspects of radioactive waste management and nuclear power plant decommissioning.

In Poland, which in the early 1990s decided to discontinue its nuclear power programme, rising demand for electricity, as well as replacement of ageing plants, will require construction of new electric power plants in years ahead. More than 60% of the country's existing power plants, predominately coal and gas-fired, have been operating for 20 years or more. More information about the seminar may be obtained from Roman Trechcinski, SEP 00-043 Warsaw, Tadeusza Czackiego 3/5, Poland. Facsimile: (22) 27-5619. Electronic mail: romtrech@cx1.cyf.gov.pl.

Algeria: Safeguards Agreement

The IAEA Board of Governors has authorized the conclusion and implementation of a comprehensive safeguards agreement with Algeria. The agreement is in connection with Algeria's obligations under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), to which the country acceded in January 1995. The Board approved the agreement at its meetings in March 1996. It covers all source or special fissionable material in all peaceful nuclear activities within the territory of Algeria, under its jurisdiction or carried out under its control anywhere, for the exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices.

The Agency has been applying safeguards in Algeria under other agreements covering the country's two research reactors that stay in effect until the new comprehensive agreement enters into force.

Monaco: Safeguards Agreement

At its meetings in March 1996, the IAEA Board of Governors authorized the conclusion and implementation of a comprehensive safeguards agreement with Monaco. It was concluded pursuant to Monaco's obligations under the Treaty on the Non-Proliferation of Nuclear Weapons, to which Monaco acceded in March 1995.

Brazil: CWC Ratification

In March 1996, Brazil became the 49th country to ratify the Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction (CWC). The government deposited its instrument of ratification with the UN Secretary-General 13 March 1996. Since it opened for signature in January 1993, the CWC has been signed by 160 States. It will enter into force 180 days after the deposit of the 65th instrument of ratification. The Convention prohibits the development, production, acquisition, retention, stockpiling, transfer and use of chemical weapons, and provides for their total destruction. More information may be obtained from the Preparatory Commission for the Organization for the Prohibition of Chemical Weapons, Laan van Meerdervoort 51, 2517 AE The Hague, Netherlands. Facsimile: 31-70-360-0944.

Fiji: USA, France & UK Sign Rarotonga Treaty Protocols

France, the United States, and the United Kingdom have signed protocols to the South Pacific Nuclear Free Zone Treaty, also known as the Treaty of Rarotonga. Signed 25 March 1996 in Suva, Fiji, the protocols bind the States not to use nuclear force or the threat of its use in the region; ban the stationing of nuclear weapons on any territory in the region; and prohibit testing of nuclear weapons there. The world's other two declared nuclear-weapon States, China and Russia, already are party to the protocols relevant to them. Parties to the Treaty, which entered into force in December 1986, include Australia, Cook Islands, Fiji, Kiribati, Nauru, New Zealand, Niue, Papua New Guinea, Solomon Islands, Tuvalu, Vanuatu, and Western Samoa.

China: World Water Day

Beijing hosted the global observance of World Water Day 22 March 1996. The Day — under the theme "Water for Thirsty Cities" — was declared to focus attention on growing water problems faced by cities in many countries. Most of the world's future population will live in urban areas, placing even greater demands on fresh water resources. Cities will have to face the challenge of supplying water and sanitation, while ensuring that available water is not wasted or contaminated. Already, the level of "unaccounted for" water in many cities ex-

H.S.H. Prince Ranier III of Monaco and IAEA Director General Hans Blix in January 1996.
(Credit: Gaëtan Luci, Palais Princier de Monaco)

ceeds 50%, notes the United Nations Conference on Human Settlements (UNCHS), which was designated the lead agency for World Water Day 1996. Water issues will be among major topics addressed in June 1996 at the Second UN Conference on Human Settlements in Istanbul.

At the IAEA, a range of programmes and services is supporting national and global efforts to identify and preserve the world's water resources. Nuclear and related applications often serve as valuable tools in ecological and hydrological studies.

Iraq: Security Council Statement

The UN Security Council on 19 March 1996 issued a statement reiterating its full support to the UN Special Commission (UNSCOM) and the IAEA in the conduct of inspections and other tasks in Iraq under terms of resolutions adopted by the Council. The statement was made in response to an UNSCOM report to the Council that Iraq had denied UN weapons inspectors access to Iraqi facilities during inspections in March 1996. Access was subsequently granted only after what the Council described as "unacceptable delays".

Excerpts from the Council's statement:

"The Security Council reiterates its full support for the Special Commission in the conduct of its inspections and the other tasks entrusted to it by the Council....It recalls that, under paragraph 9 (b)(i) of section C of Security Council resolution 687 (1991), Iraq is required to permit 'immediate on-site inspection of Iraq's biological, chemical and missile capabilities...By its resolution 707 (1991), the Council also expressly demanded that Iraq allow the Special Commission, the International Atomic Energy Agency and their inspection teams immediate, unconditional and unrestricted access to any and all areas, facilities, equipment, records and means of transportation which they wish to inspect'....The Security Council considers that Iraq's delays in permitting the inspection team recently in Iraq access to the sites concerned constitute clear violations by Iraq of the provisions of resolutions 687 (1991), 707 (1991) and 715 (1991). The Council demands that the Government of Iraq allow the Special Commission inspection teams immediate, unconditional and unrestricted access to all sites designated by the Commission for inspection in accordance with the relevant resolutions of the Council."

Thailand: South East Asian NWFZ

Thailand and the IAEA have opened preliminary discussions concerning relevant provisions of the South East Asian Nuclear-Weapon-Free-Zone (NWFZ) Treaty. The Treaty, for which Thailand is the Depositary Government, was signed in Bangkok 15 December 1995 by 10 States: Brunei, Indonesia, Malaysia, Philippines, Singapore, Thailand, Viet Nam (all members of the Association of South East Asian Nations or ASEAN) and Cambodia, Laos, and Myanmar.

In his statement to the Agency's Board of Governors in March 1996, IAEA Director General Hans Blix noted that the Treaty, similar to other NWFZ treaties, requires its parties to conclude agreements with the IAEA for the application of comprehensive safeguards. It also contains a number of other provisions, ranging from nuclear safety to the conditions applicable to the supply of nuclear items. These include the requirement that peaceful nuclear activities in the NWFZ are subject to safety assessments conforming to the guidelines and standards recommended by the IAEA. The Treaty, with respect to its control system, also makes provision for fact-finding missions which would be conducted by inspectors of the IAEA.

Egypt: African NWFZ Treaty

Unanimously approved by the UN General Assembly in December 1995, the African Nuclear-Weapon-Free-Zone Treaty opened for signature in Cairo 11 April 1995. Among those invited to attend the signing ceremony were Heads of State and Foreign Ministers of the 53 States that are members of the Organization for African Unity, UN Secretary-General Boutros-Ghali, IAEA Director General Hans Blix, and IAEA Assistant Director General Mohamed ElBaradei, who heads the IAEA Division of External Relations. The IAEA supported the negotiations on the Treaty through a number of General Conference resolutions and the provision of advice on technical and legal aspects.

The Treaty is open for signature to any State in the African nuclear-weapon-free-zone, and it will enter into force on the date of deposit of the 28th instrument of ratification.

Russian Federation: Radioactive Waste Management

An expert group established by the IAEA on ways to enhance international co-operation with the Russian Federation in areas of radioactive waste management met in Moscow in early 1996. Participating in the meeting were representatives from 12 countries — Belgium Canada, Finland, France, Germany, Japan, Republic of Korea, Norway, Russian Federation, Sweden, the United Kingdom, and the United States — and from four international organizations, including the European Commission. Among items discussed were proposed co-operative activities and the possible role of the IAEA in supporting the work.

The meeting is part of activities following an international seminar that the Agency convened in May 1995. The seminar was organized in response to a request of the Joint Council of the Nordic countries and with the approval of the Russian Federation. The seminar included presentations on co-operative programmes in areas of radioactive waste management with Russia, and reports on Russia's waste management programme, structure, and problems. One aim was to identify priority areas where enhanced international co-operation would be useful for strengthening radioactive waste management in the Russian Federation.

Belarus, Russian Federation & Ukraine: Chernobyl Conference

The first International Conference of the European Commission (EC), Belarus, Russian Federation and Ukraine was convened in Minsk 18-22 March 1996. The Conference covered a range of topics related to the social, health, and environmental consequences of the April 1986 accident in the three States and Europe. Results were reported to an International Conference on Chernobyl in April 1996 convened by the IAEA, EC, and World Health Organization in Vienna. *(See related item, page 45).* More information may be obtained from the EC, rue de la Loi 200, B-1049 Brussels, Belgium. Facsimile: (32-1) 296-6256.

United States: Energy Forecasts

Electricity plants in the United States produce about 36% of national carbon emissions from energy production, and their share is expected to increase to 38% by the year 2015, based on projections in the 1996 edition of the *Annual Energy Outlook,* a report prepared by the US Department of Energy's Energy Information Administration (EIA). The rising share is attributed to greater reliance on coal for the production of electricity. Currently, coal accounts for 52% of total US electricity generation but produces 87% of electricity-related carbon emissions, the EIA report states. Natural gas and oil account for the remainder of carbon emissions.

Nuclear electricity generation — which today provides about one-fifth of US electricity — is projected to decline between now and 2015, the report states, by about 32%, as 37 gigawatts of nuclear capacity are expected to be retired. To meet electricity demand, about 230 gigawatts of new capacity will be needed. If the required electricity is produced from fossil fuels, carbon emissions will increase by 160 million metric tons, or 32%, over current levels, the report states. More information may be obtained from the EIA, Forrestal Building, Room 1F-048, Washington, DC 20585 USA. The electronic mail address of the EIA's National Energy Information Center is infoctr@eia.doe.gov.

Mexico: Public Information Seminar

Mexico's President Ernesto Zedillo Ponce de León is expected to address an IAEA-sponsored public information seminar scheduled in Mexico City 18-20 June 1996. The Regional Seminar on Atoms for Development — organized within the framework of an extrabudgetary programme funded by Japan — is being hosted by Mexico's National Institute of Nuclear Research (NINR). Other speakers include Dr, Miguel José Yacaman, NINR Director; IAEA Director General Hans Blix; and experts from Mexico and the IAEA. Topics on the agenda include nuclear power and safety and nuclear applications in health and other fields.

NUCLEAR ENERGY INSTITUTE (NEI). The Nuclear Energy Institute in the United States has elected a new President and Chief Operating Officer. He is Mr. Joe F. Colvin, formerly President and Chief Executive Officer (CEO) of the Nuclear Management and Resources Council, an NEI predecessor organization. He succeeds Mr. Phillip Bayne, who continues as NEI's CEO until 29 June 1996. Mr. Colvin's previous experience includes seven years with the Institute of Nuclear Power Operations where he was instrumental in developing key programmes to assist the industry in achieving excellence in operations. He also spent a distinguished 20-year career as a nuclear submarine officer in the US Navy.

Web Site. In other news, NEI has announced the opening of its Internet site on the World Wide Web. The on-line information network includes access to fact sheets, organizational information, press statements, reports, and other products. The site is located at the Internet address http://www.nei.org/ NEI, based in Washington, DC, is the trade organization of US nuclear industries, including electric utilities that own and operate the nation's more than 100 nuclear power plants.

EMERGENCY PLANNING COURSE. Belgium's Study Centre for Nuclear Energy (SCK-CEN) is holding its sixth training course on off-site emergency response to nuclear accidents 1-5 July 1996 in Mol. The course is being conducted in collaboration with the European Commission. More information may be obtained from A. Sohier, SCK-CEN, B-2400 Mol, Belgium. Facsimile: 32-14-321056.

NUCLEAR STUDIES AND REPORTS. The Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development has published two new studies on aspects of nuclear development. A new analytical study of nuclear legislation in NEA countries — *Regulatory and Institutional Framework for Nuclear Activities* — provides a global and systematic picture of nuclear laws in 25 countries. It also provides a collection of information covering the institutional framework for nuclear energy in each country, together with the main sectors of nuclear energy, including mining regimes, trade in nuclear materials and equipment, radioactive waste management, and radiation protection. Another recent report — *Chernobyl, Ten Years On: Radiological and Health Impact* — is an informative appraisal of the Chernobyl accident's consequences by the NEA Committee on Radiation Protection and Public Health. More information may be obtained from NEA, Le Seine St-Germain, 12, boulevard des Îles, 92130 Issy-les-Moulineaux, France. Facsimile: 33-1-45241110.

CONVENTIONS ON NUCLEAR SAFETY AND RADIOACTIVE WASTE. Sixty-three States have signed the Nuclear Safety Convention as of March 1996. Instruments of ratification have been deposited by 16 States, eleven of which are countries having nuclear power programmes. Ratification of 22 States, including 17 nuclear power countries, is required to bring the Convention into force. A number of countries are in advanced stages of the ratification process. Progress also continues under IAEA auspices in the development of the Convention on the Safe Management of Radioactive Waste. Three preparatory meetings have taken place and a fourth is scheduled in the coming months. It is expected that a draft text could be ready by the end of this year.

TRANSPORT REGULATIONS FOR RADIOACTIVE MATERIALS. The Agency's *Regulations for the Safe Transport of Radioactive Materials* are being revised. They have long formed the basis for regulating national and international surface, water, and air shipments of radioactive material. The revised regulations are expected to be submitted to the IAEA Board of Governors in June 1996. A number of international organizations — including the London-based International Maritime Organization (IMO) and the Montreal-based International Civil Aviation Organization (ICAO) — have collaborated in the development of the IAEA's transport regulations. Additionally, the IMO has produced a code addressing the construction and operation specifications for vessels transporting radioactive material.

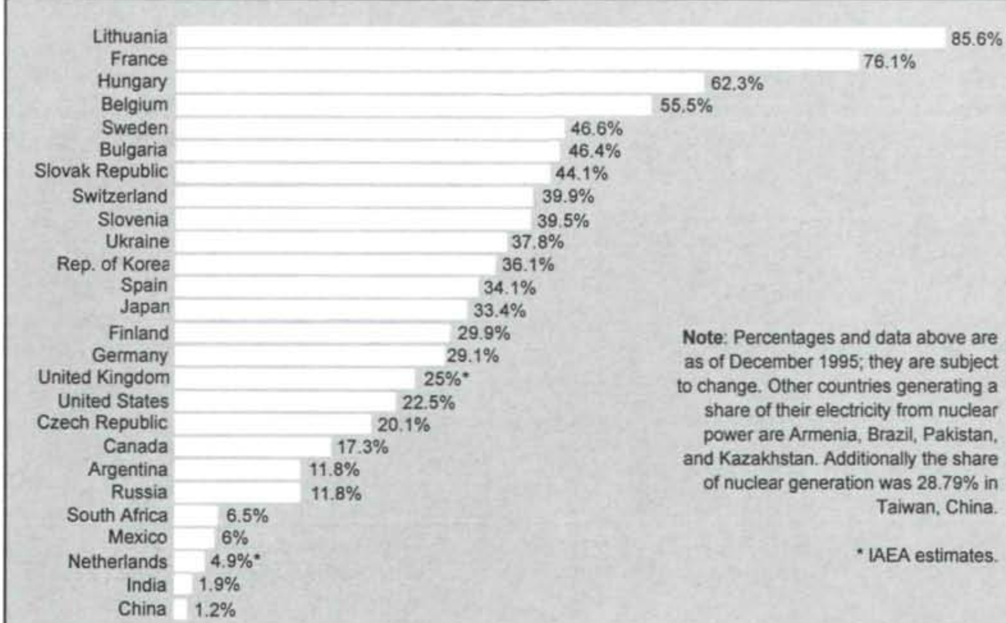
Nuclear power status around the world

	In operation		Under construction	
	No. of units	Total net MWe	No. of units	Total net MWe
Argentina	2	935	1	692
Armenia	1	376		
Belgium	7	5 527		
Brazil	1	626	1	1245
Bulgaria	6	3 538		
Canada	21	14 907		
China	3	2 167		
Czech Republic	4	1 648	2	1 824
Finland	4	2 310		
France	56	58 493	4	5 810
Germany	20	22 017		
Hungary	4	1 729		
India	10	1 695	4	808
Iran			2	2 146
Japan	51	39 917	3	3 757
Kazakhstan	1	70		
Korea, Rep. of	11	9 120	5	3 870
Lithuania	2	2 370		
Mexico	2	1 308		
Netherlands	2	504		
Pakistan	1	125	1	300
Romania			2	1 300
Russian Federation	29	19 843	4	3 375
South Africa	2	1 842		
Slovak Republic	4	1 632	4	1 552
Slovenia	1	632		
Spain	9	7 124		
Sweden	12	10 002		
Switzerland	5	3 050		
United Kingdom	35	12 908		
Ukraine	16	13 629	5	4 750
United States	109	98 784	1	1 165
World total*	437	343 712	39	32 594

* The total includesTaiwan, China where six reactors totalling 4884 MWe are in operation.

Notes to table: Data are subject to revision. During 1995, two reactors were shutdown (including Bruce-2 in Canada which could restart in the future); seven reactors were connected to the grid; and the construction of three reactors was temporarily suspended (in Romania).

Nuclear share of electricity generation in selected countries



Note: Percentages and data above are as of December 1995; they are subject to change. Other countries generating a share of their electricity from nuclear power are Armenia, Brazil, Pakistan, and Kazakhstan. Additionally the share of nuclear generation was 28.79% in Taiwan, China.

* IAEA estimates.

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A-1400 Vienna, Austria
Telephone: +43 1 2060 (22529, 22530)
Facsimile: +43 1 2060 29302
Electronic mail:
SALESPUB@ADPO1.IAEA.OR.AT

POSTS ANNOUNCED BY THE IAEA

NUCLEAR/CHEMICAL ENGINEER (96-027), Department of Nuclear Energy, Waste Technology Section. This P-5 post serves as Unit Leader, carrying responsibilities for the development and implementation of programmes on technologies, practices, and policies pertaining to the handling, treatment, conditioning, and storage of radioactive wastes. It requires a Ph.D. or equivalent advanced university degree in chemical or nuclear sciences or engineering and at least 15 years of experience in processing of radioactive wastes. *Closing date: 29 July 1996.*

NUCLEAR ENGINEER (96-026), Department of Nuclear Energy, Nuclear Fuel Cycle and Materials Section. This P-5 post formulates, plans, and implements activities of the programme on the management of spent fuel. It requires a Ph.D. or equivalent university degree in engineering/physics, chemistry and metallurgy and at least 15 years of experience in the area of spent fuel management.
Closing date: 29 July 1996.

HEAD OF DOSIMETRY LABORATORY (96-025), Department of Research & Isotopes. This P-4 post requires a Ph.D. or equivalent university degree in physics with at least 10 years of practical experience in the field of radiation dosimetry. From these, at least 5 years are required in a Standard Dosimety Laboratory or as a radiotherapy hospital physicist. Also required is experience in high-accuracy experimental methods with ionization chamber and TLD dosimetry at therapy and protection levels.
Closing date: 29 July 1996.

SECTION HEAD (96-024), Department of Administration, Division of General Services. This P-5 post requires an advanced university degree in economic or business administration and 15 years of progressively more responsible experience in the field of budgetary and financial matters, inventory control, supply service, transportation or sales. Some of this experience should be at a senior managerial level with a commercial, national or international organization. Also required is experience with EDP applications in financial, budget and stock control systems and knowledge of the principles of human resources and financial management.
Closing date: 29 July 1996.

SECTION HEAD (96-023), Department of Safeguards, Training Section. This P-5 post requires an advanced university degree (or equivalent) in science, engineering or education and formal training in instructional design technology, and a minimum of 15 years experience in research, industry or the nuclear field with substantial experience in directing or conducting training programmes, as well as knowledge and experience with non-proliferation issues or international safeguards.
Closing date: 22 July 1996.

ISOTOPE HYDROLOGIST (96-022), Department of Research & Isotopes. This P-3 post requires a Ph.D. in hydrology, physics or chemistry, and at least 6 years of demonstrated research experience in the application of isotope techniques in hydrological and environmental disciplines such as global changes, palaeohydrology and palaeoclimatology.
Closing date: 22 July 1996.

UNIT HEAD (96-021), Department of Nuclear Energy, Division of Scientific and Technical Information. This P-4 post requires a university degree in a subject area covered by INIS, and 10 years national level experience in the management, production, and dissemination of technical or scientific information. Also required is experience in the management of bibliographic databases and familiarity with computer technology, and at least five years in a supervisory capacity.
Closing date. 22 July 1996.

SECTION HEAD (96-020), Department of Nuclear Energy, Waste Technology Section. This P-5 post requires a university degree in nuclear or chemical engineering, nuclear chemistry, physics or environmental science, and 15 years of relevant experience with at least 5 years managerial experience. Also required is knowledge of the principles and practices of human resources and financial management, and ability to apply this knowledge in allocating and managing assigned resources. *Closing date: 28 June 1996.*

HEAD PHYSICS, CHEMISTRY & INSTRUMENTATION LABORATORY (96-019), Department of Research & Isotopes. This P-5 post requires a Ph.D. or equivalent degree in chemistry, with emphasis in nuclear/radiochemistry, nuclear physics, or nuclear or electronics engineering. Also required is 15 years of professional experience in a management position in multi disciplinary institutions dealing with nuclear and related matters.
Closing date: 28 June 1996.

DEVELOPMENT PROGRAMMER (96-018), Department of Nuclear Energy. This P-2 post requires a university degree in computer science or related field and at least 2 years practical programming experience, knowledge of MS-DOS, MS Windows, Visual Basic, C/C++ and SQL. *Closing date: 28 June 1996.*

DIRECTOR (96-016), Department of Administration, Legal Division. This D-1/D-2 post requires an advanced university degree in law and extensive experience in the fields of international law, the law of intergovernmental organizations or law relating to the peaceful uses of atomic energy. *Closing date: 7 June 1996.*

NUCLEAR PHYSICIST (96-014), Department of Research & Isotopes. This P-4 post requires a Ph.D. or equivalent degree in nuclear physics followed by at least ten years of relevant research experience and expertise in measurements, theory, evaluation or application of nuclear data, and familiarity with nuclear data needs for specific energy or non-energy applications. Also required is experience in computer physics, processing of nuclear data files and related programming. *Closing date: 7 June 1996.*

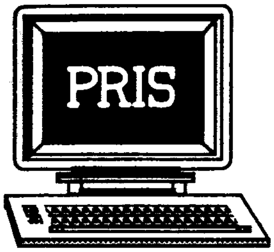
READER'S NOTE:

The *IAEA Bulletin* publishes short summaries of vacancy notices as a service to readers interested in the types of professional positions required by the IAEA. They are ***not*** the official notices and remain subject to change. On a frequent basis, the IAEA sends vacancy notices to governmental bodies and organizations in the Agency's Member States (typically the foreign ministry and atomic energy authority), as well as to United Nations offices and information centres. Prospective applicants are advised to maintain contact with them. Applications are invited from suitable qualified women as well as men. More specific information about employment opportunities at the IAEA may be obtained by writing the Division of Personnel, Box 100, A-1400 Vienna, Austria.

ON-LINE COMPUTER SERVICES. IAEA vacancy notices for professional positions, as well as application forms, now are available through a global computerized network that can be accessed directly. Access is through the Internet. The vacancy notices are located in a public directory accessible via the normal Internet file transfer services. To use the service, connect to the IAEA's Internet address at NESIRS01.IAEA.OR.AT (161.5.64.10), and then log on using the identification *anonymous* and your user identification. The vacancy notices are in the directory called *pub/vacancy_posts*. A *README* file contains general information, and an *INDEX* file contains a short description of each vacancy notice. Other information, in the form of files that may be copied, includes an application form and conditions of employment. Please note that applications for posts cannot be forwarded through the computerized network, since they must be received in writing by the IAEA Division of Personnel.

ON LINE DATABASES

OF THE INTERNATIONAL ATOMIC ENERGY AGENCY



Database name
Power Reactor Information System (PRIS)

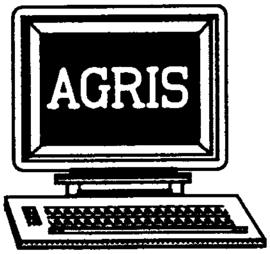
Type of database
Factual

Producer
International Atomic Energy Agency in co-operation with 29 IAEA Member States

IAEA contact
IAEA, Nuclear Power Engineering Section, P.O. Box 100
A-1400 Vienna, Austria
Telephone (43) (1) 2060
Telex (1)-12645
Facsimile +43 1 20607
Electronic mail via BITNET/INTERNET to ID: NES@IAEA1.IAEA.OR.AT

Scope
Worldwide information on power reactors in operation, under construction, planned or shutdown, and data on operating experience with nuclear power plants in IAEA Member States.

Coverage
Reactor status, name, location, type, supplier, turbine generator supplier, plant owner and operator, thermal power, gross and net electrical power, date of construction start, date of first criticality, date of first synchronization to grid, date of commercial operation, date of shutdown, and data on reactor core characteristics and plant systems; energy produced; planned and unplanned energy losses; energy availability and unavailability factors; operating factor, and load factor.



Database name
International Information System for the Agricultural Sciences and Technology (AGRIS)

Type of database
Bibliographic

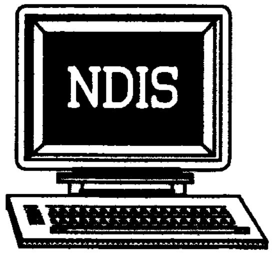
Producer
Food and Agriculture Organization of the United Nations (FAO) in co-operation with 172 national, regional, and international AGRIS centres

IAEA contact
AGRIS Processing Unit
c/o IAEA, P.O. Box 100
A-1400 Vienna, Austria
Telephone (43) (1) 2060
Telex (1)-12645
Facsimile +43 1 20607
Electronic mail via BITNET/INTERNET to ID: FAS@IAEA1.IAEA.OR.AT

Number of records on line from January 1993 to date
more than 130 000

Scope
Worldwide information on agricultural sciences and technology, including forestry, fisheries, and nutrition.

Coverage
Agriculture in general; geography and history; education, extension, and information; administration and legislation; agricultural economics; development and rural sociology; plant and animal science and production; plant protection; post-harvest technology; fisheries and aquaculture; agricultural machinery and engineering; natural resources; processing of agricultural products; human nutrition; pollution; methodology.



Database name
Nuclear Data Information System (NDIS)

Type of database
Numerical and bibliographic

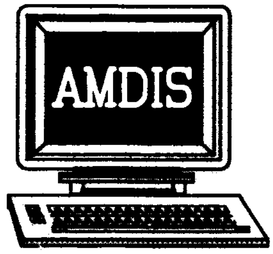
Producer
International Atomic Energy Agency in co-operation with the United States National Nuclear Data Centre at the Brookhaven National Laboratory, the Nuclear Data Bank of the Nuclear Energy Agency, Organisation for Economic Co-operation and Development in Paris, France, and a network of 22 other nuclear data centres worldwide

IAEA contact
IAEA Nuclear Data Section,
P.O. Box 100
A-1400 Vienna, Austria
Telephone (43) (1) 2060
Telex (1)-12645
Facsimile +43 1 20607
Electronic mail via BITNET/INTERNET to ID: RNDS@IAEA1.IAEA.OR.AT

Scope
Numerical nuclear physics data files describing the interaction of radiation with matter, and related bibliographic data.

Data types
Evaluated neutron reaction data in ENDF format; experimental nuclear reaction data in EXFOR format, for reactions induced by neutrons, charged particles, or photons; nuclear half-lives and radioactive decay data in the systems NUDAT and ENSDF; related bibliographic information from the IAEA databases CINDA and NSR; various other types of data.

Note: Off-line data retrievals from NDIS also may be obtained from the producer on magnetic tape



Database name
Atomic and Molecular Data Information System (AMDIS)

Type of database
Numerical and bibliographic

Producer
International Atomic Energy Agency in co-operation with the International Atomic and Molecular Data Centre network, a group of 16 national data centres from several countries.

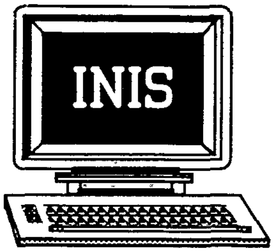
IAEA contact
IAEA Atomic and Molecular Data Unit, Nuclear Data Section
Electronic mail via BITNET to: RNDS@IAEA1;
via INTERNET to ID: PSM@RIPCRS01.IAEA.OR.AT

Scope
Data on atomic, molecular, plasma-surface interaction, and material properties of interest to fusion research and technology

Coverage
Includes ALADDIN formatted data on atomic structure and spectra (energy levels, wave lengths, and transition probabilities); electron and heavy particle collisions with atoms, ions, and molecules (cross sections and/or rate coefficients, including, in most cases, analytic fit to the data); sputtering of surfaces by impact of main plasma constituents and self sputtering; particle reflection from surfaces; thermophysical and thermomechanical properties of beryllium and pyrolytic graphites.

Note: Off-line data and bibliographic retrievals, as well as ALADDIN software and manual, also may be ob-tained from the producer on diskettes, magnetic tape, or hard copy.

For access to these databases, please contact the producers.
Information from these databases also may be purchased from the producer in printed form.
INIS and AGRIS additionally are available on CD-ROM.



Database name
International Nuclear Information System (INIS)

Type of database
Bibliographic

Producer
International Atomic Energy Agency in co-operation with 91 IAEA Member States and 17 other international member organizations

IAEA contact
IAEA, INIS Section, P.O. Box 100, A-1400 Vienna, Austria
Telephone (+431) 2060 22842
Facsimile (+431) 20607 22842
Electronic mail via BITNET/INTERNET to ID: ATIEH@NEPO1.IAEA.OR.AT

Number of records on line from January 1976 to date
more than 1.6 million

Scope
Worldwide information on the peaceful uses of nuclear science and technology; economic and environmental aspects of other energy sources.

Coverage
The central areas of coverage are nuclear reactors, reactor safety, nuclear fusion, applications of radiation or isotopes in medicine, agriculture, industry, and pest control, as well as related fields such as nuclear chemistry, nuclear physics, and materials science. Special emphasis is placed on the environmental, economic, and health effects of nuclear energy, as well as, from 1992, the economic and environmental aspects of non-nuclear energy sources. Legal and social aspects associated with nuclear energy also are covered.

IAEA UPCOMING CO-ORDINATED RESEARCH PROGRAMMES

Dose determination with plane-parallel ionization chambers in therapeutic electron and photon beams
To investigate the accuracy of the data and procedures included in the new code of practice. In addition, differences with existing recommendations will be quantified to analyze the possible impact in patient dosimetry.

Compilation and evaluation of photonuclear data for applications
To develop a data file of evaluated photonuclear reaction cross sections. The list of nuclei should include natural elements and isotopes of importance in biological, structural and shielding materials, as well as actinides, fission products and a few others.

Assuring structural integrity of reactor pressure vessel
To facilitate the international exchange of information, provide practical guidance in the field of monitoring reactor pressure vessels and to develop and assess a uniform procedure of testing specimens for the assessment of RPV structural integrity.

Development of radiological basis for the transport safety requirements for low specific activity materials and surface contaminated objects
To assist the Agency in developing transport safety requirements. This CRP will provide a basis for classifying low level radioactive materials (such as low level waste) and for modelling potential releases in the event of transport accidents.

Development of methodologies for optimization of surveillance testing and maintenance of safety related equipment at nuclear power plants
To provide an exchange of experience in investigating and analyzing different strategies to improve and optimize maintenance and surveillance testing focusing on nuclear power plant safety, and to stimulate the exchange of methodologies and techniques to carry out such optimization processes.

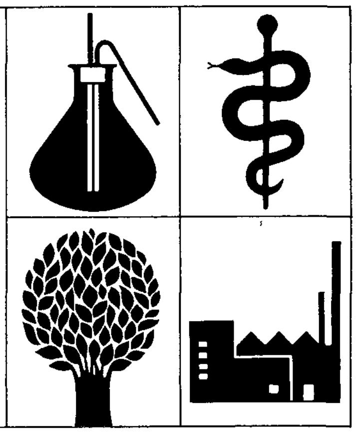
Biosphere Modelling and Assessment methods (BIOMASS)
To analyze and quantify the behaviour of radionuclides in the biosphere in support of assessments of the radiological impact of practices and interventions related to nuclear fuel cycle activities, including waste management.

Modelling transport of radioactive substances in primary circuit of water cooled reactors
To compare and improve computer codes for modelling the transport of radioactive substances in the reactor primary systems.

Reference Asian Man Project (Phase 2): Ingestion and organ content of trace elements of importance in radiological protection
To obtain high quality analytical data on dietary intakes (ingestion) and body composition of representative Asian populations, with special reference to trace elements that are of importance in radiological protection.

Use of radiation processing to prepare biomaterials for applications in medicine
To promote research and development of materials for use in medicine and industry, applying methods of radiation synthesis and technology.

These are selected listings, subject to change More complete information about IAEA meetings can be obtained from the IAEA Conference Service Section at the Agency's headquarters in Vienna, or by referring to the IAEA quarterly publication ***Meetings on Atomic Energy*** (See the *Keep Abreast* section for ordering information.) More detailed information about the IAEA's co-ordinated research programmes may be obtained from the Research Contracts Administration Section at IAEA headquarters The programmes are designed to facilitate global co-operation on scientific and technical subjects in various fields, ranging from radiation applications in medicine, agriculture, and industry to nuclear power technology and safety.



IAEA SYMPOSIA & SEMINARS

JULY 1996

FAO/IAEA Symposium on the Use of Nuclear and Related Techniques for Studying Environmental Behaviour of Crop Protection Chemicals
Vienna, Austria (1 - 5 July)

AUGUST 1996

Seminar on Nuclear Techniques for the Detection and Management of Cancer
Colombo, Sri Lanka (12 -16 August)

SEPTEMBER 1996

IAEA General Conference, 40th session
Vienna, Austria
(16 - 20 September)

OCTOBER 1996

16th IAEA Fusion Energy Conference
Montreal, Canada (7 - 11 October)

Symposium on Reviewing the Safety of Existing Nuclear Power Plants
Vienna, Austria (8 - 11 October)

A Seminar on Safeguards 1996 and Beyond
Vienna, Austria (28 - 30 October)

NOVEMBER 1996

Symposium on Harmonization of Health-Related Environmental Measurements Using Nuclear Analytical Techniques
Hydrabad, India (4 -7 November)

Seminar on the Use of Isotope Techniques in Marine Environmental Studies
Venue to be announced
(11-22 November)

APRIL 1997

Symposium on Diagnosis and Control of Livestock Diseases Using Nuclear and Related Techniques
Vienna, Austria

International Symposium on Applications of Isotope Techniques in Studying Past and Current Environmental Changes in the Hydrosphere and the Atmosphere
Vienna, Austria

JUNE 1997

Symposium on Nuclear Fuel Cycle and Reactor Strategies — Adjusting to New Realities
Vienna, Austria (2-6 June)

OCTOBER 1997

Seminar on Nuclear Techniques for Optimizing the Use of Nutrients and Water for Plant Productivity and Environmental Preservation
Venue to be announced

96-00527

IAEA BULLETIN

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Iran, Islamic Republic of
Luxembourg
Mexico
Philippines
Sudan

1959
Iraq

1960
Chile
Colombia
Ghana
Senegal

1961
Lebanon
Mali
Zaire

1962
Liberia
Saudi Arabia

1963
Algeria
Bolivia
Côte d'Ivoire
Libyan Arab Jamahiriya
Syrian Arab Republic
Uruguay

1964
Cameroon
Gabon
Kuwait
Nigeria

1965
Costa Rica
Cyprus
Jamaica
Kenya
Madagascar

1966
Jordan
Panama

1967
Sierra Leone
Singapore
Uganda

1968
Liechtenstein

1969
Malaysia
Niger
Zambia

1970
Ireland

1972
Bangladesh

1973
Mongolia

1974
Mauritius

1976
Qatar
United Arab Emirates
United Republic of Tanzania

1977
Nicaragua

1983
Namibia

1984
China

1986
Zimbabwe

1991
Latvia
Lithuania

1992
Croatia
Estonia
Slovenia

1993
Armenia
Czech Republic
Slovakia

1994
Former Yugoslav Republic of Macedonia
Kazakhstan
Marshall Islands
Uzbekistan
Yemen

1995
Bosnia and Herzegovina
Georgia

Eighteen ratifications were required to bring the IAEA's Statute into force. By 29 July 1957, the States in bold face had ratified the Statute.

Year denotes year of membership. Names of the States are not necessarily their historical designations.

For States in italic, membership has been approved by the IAEA General Conference and will take effect once the required legal instruments have been deposited.

The International Atomic Energy Agency, which came into being on 29 July 1957, is an independent intergovernmental organization within the United Nations System. Headquartered in Vienna, Austria, the Agency has more than 100 Member States who together work to carry out the main objectives of IAEA's Statute: To accelerate and enlarge the contribution of atomic energy to peace, health, and prosperity throughout the world and to ensure so far as it is able that assistance provided by it, or at its request or under its supervision or control, is not used in such a way as to further any military purpose.

IAEA headquarters, at the Vienna International Centre.

Until now, one of the biggest problems with reading personal exposure doses has been the size of the monitoring equipment. Which is precisely why we're introducing the Electronic Pocket Dosimeter (EPD) "MY DOSE mini™" PDM-Series.

These high-performance dosimeters combine an easy-to-read digital display with a wide measuring range suiting a wide range of needs.

But the big news is how very small and lightweight they've become. Able to fit into any pocket and weighing just 50~90 grams, the Aloka EPDs can go anywhere you go. Which may prove to be quite a sizable improvement, indeed.

Model	Energy	Range	Application
PDM-101	60 keV ~	0.01 ~ 99.99 μSv	High sensitivity, photon
PDM-102	40 keV ~	1 ~ 9,999 μSv	General use, photon
PDM-173	40 keV ~	0.01 ~ 99.99 mSv	General use, photon
PDM-107	20 keV ~	1 ~ 9,999 μSv	Low energy, photon
PDM-303	thermal ~ fast	0.01 ~ 99.99 mSv	Neutron
ADM-102	40 keV ~	0.001 ~ 99.99 mSv	With vibration & sound alarm, photon

SCIENCE AND HUMANITY

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