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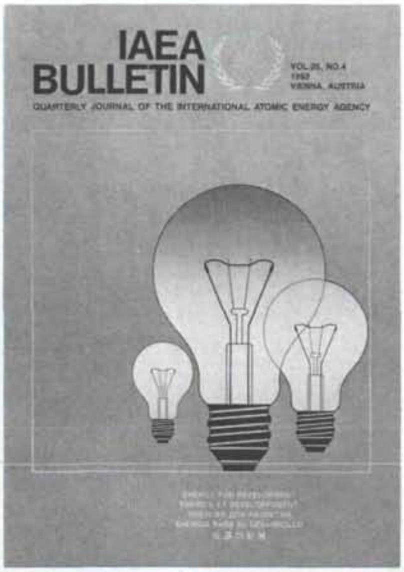
ЭНЕРГИЯ ДЛЯ РАЗВИТИЯ
ENERGIA PARA EL DESARROLLO
能源与发展



Front cover: Countries where nuclear energy is an important source of electricity have been able to cut their atmospheric emissions of CO_2 — a "greenhouse" gas — dramatically over the past decade. As reported in this edition of the *IAEA Bulletin*, studies show that CO_2 emissions can be reduced even more if nuclear energy's share of electricity markets is able to grow around the world. To realistically assess their options for electricity generation, many countries in Asia, Latin America, and other regions are drawing upon the IAEA's range of technical and advisory services. Energy needs are great. In Asia alone — where population growth rates are among the world's highest — investments in electric power systems of about US $500 billion are needed to sustain national economies and meet projected electricity demand during this decade. *(Cover design: Ms. Hannelore Wilczek, IAEA)*

Facing page: Step-by-step up the cooling tower, a worker heads for a bird's eye view of the Bugey nuclear power plant in France, where about 75% of all electricity is generated by nuclear energy. *(Credit: Setboun/Rapho Agence de Presse, Paris)*

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Nuclear power development in Asia

Fast-growing national economies and electricity needs are driving plans to introduce or expand the use of nuclear power

by Chuanwen Hu
and
Georg Woite

Asia — the continent with the largest population in the world — has achieved significant economic growth within the past decades. In many countries, the rapid population and economic growth has brought a tremendous demand for energy and electricity — one which fossil fuels and hydropower together will not be able to meet. Nuclear power is thus expected to become an important option for meeting the region's long-term electricity needs on a sustainable basis.

In Japan and the Republic of Korea, for example, successful and ongoing nuclear programmes now account for a large share of total electricity generation. The People's Republic of China and India, as the world's two largest developing countries, are actively proceeding with national nuclear energy programmes. Several other Asian countries have announced their intentions to consider nuclear power deployment in their long-term energy plans.

This article examines recent energy developments in the region, and most specifically the status and prospects of nuclear power. In so doing, it briefly reviews aspects of population and economic growth, energy demand, and environmental and financial constraints of energy supply in Asia, and looks at diverse national situations concerning the potential role of nuclear energy.

Economic and energy developments

Nearly 60% of the world's people live in Asia, where most countries have quite low levels of gross national product and *per capita* energy consumption. South Asia is one of the regions with the highest population growth rates in the world, and this trend is expected to continue up to the end of this century and beyond. Most people live in rural regions and they use very little commercial energy. Greater urbanization and improving living standards in the future, however, will lead to higher demand for energy supply with growing emphasis on commercial energy, in particular electricity. Rapidly growing economies in many Asian countries are driving forces for increased energy demand. This situation has aggravated existing power shortages in the region, and power cuts and rationed supply are routine in municipal areas.

Electricity use *per capita* in most Asian countries is substantially lower than that of industrialized countries. As compared with more than 10 000 kWh *per capita* per year in the USA, Sweden, and Canada, the electricity uses *per capita* per year in India and China were only 305 and 515 kWh in 1989, respectively. Electric system expansion is urgent for sustaining national economies.

In China, to support the country's rapid economic growth (over 10% per annum) during the past decade, the total installed electrical generating capacity has more than doubled, reaching 150 gigawatts (GWe) in 1991. In spite of this rapid increase, the electricity supply has been falling far short of demand in the fast-developing coastal areas of China. Twelve to 15 GWe of new capacity is expected annually up to the end of this century, when the total electrical generating capacity in China will reach about 260 GWe.

In India, power generating capacity was increased by about 5 GWe per year during the 1985-90 period. However, a peak deficit of more than 10 GWe and a power shortage of nearly 21 billion kWh were estimated for 1991 in India. The Indian Government's 1992-97 economic plan envisages a need for an additional 31 GWe of public-sector generating capacity.

In Indonesia, the generating capacity has doubled during the past 10 years, but it will have to be doubled again by 2000 to meet the estimated 10% annual growth in demand. The nation needs to install 35 GWe of additional capacity by 2015.

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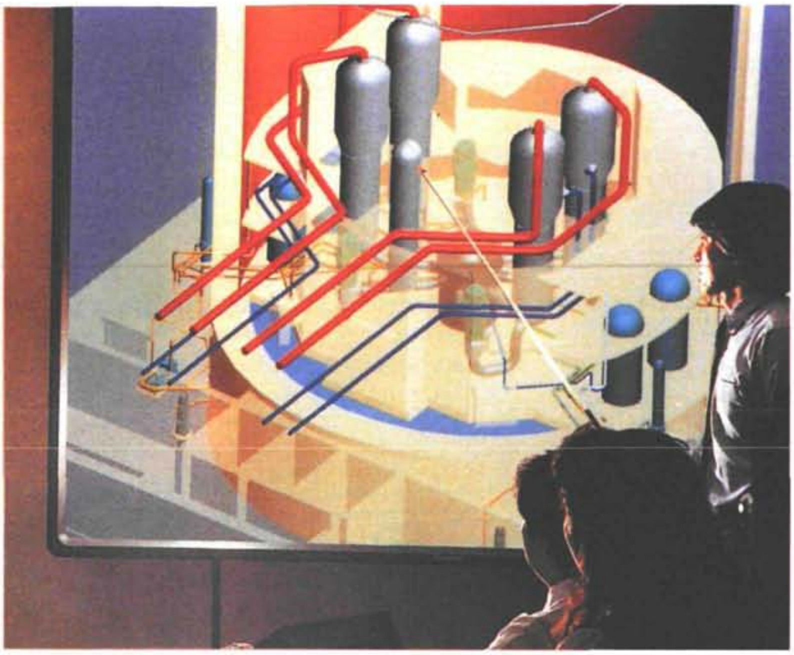
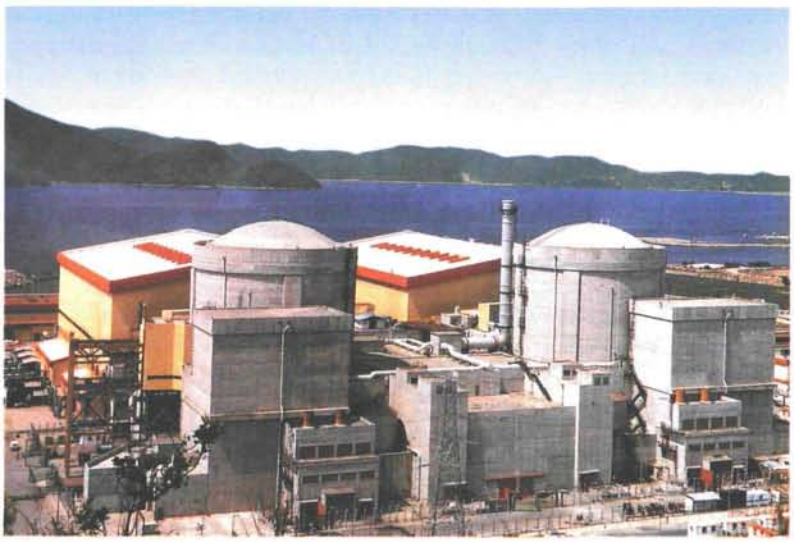
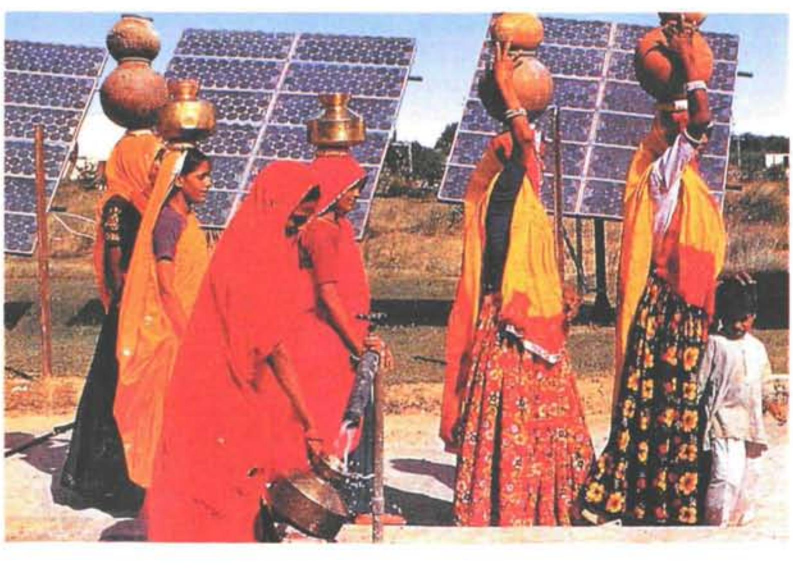
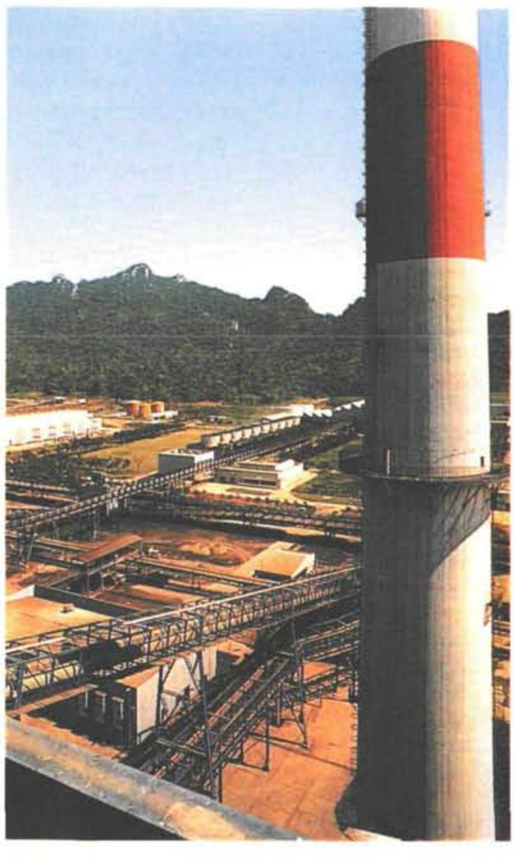




To meet Asia's rising electricity demands, nuclear power is among various energy sources being developed. *From top left:* New designs for nuclear plants being discussed in Japan; maintaining electric power lines in Indonesia; China's Guangdong nuclear plant at Daya Bay; solar panels in an Indian village; a coal-fired plant in Thailand.

(Credits: Mitsubishi; EdF; UNDP; ADB, HKNIC)





In Malaysia, electricity consumption rose 8% in 1989 and 15% in 1990. Malaysia's demand for power will almost triple by the end of the decade, to about 13 GWe from about 5 GWe now.

In Thailand, electricity capacity has rapidly increased in recent years (5.6% in 1989; 17% in 1990) and about 1 GWe of new capacity is needed every year.

In the Republic of Korea, electricity demand rose by about 13% to 14% annually between 1987-90. It is expected to rise about 4.5% to 6% per year until the year 2006.

It is estimated that throughout Asia soaring economic growth will lead to the doubling of electricity demand during the 1990s. The annual estimated additional power capacity needed in Asia is about 20 GWe per year, totalling nearly 200 GWe over the next decade.

Constraints on energy supply

At the present time, there is a big gap between energy supply and demand in Asia. Many diverse issues have obstructed the implementation of ambitious energy programmes that were planned. In the following sections, some major factors are investigated for different countries.

Resources. Several Asian countries, such as Japan (the world's largest importer of energy) and the Republic of Korea, have depended heavily on imported fuel for energy supply. The painful experience during the oil crises of the 1970s in these countries had major impacts on national energy policies. In order to ensure the long-term availability of energy, sustained and well-planned nuclear power programmes have been implemented in Japan, Republic of Korea and Taiwan, China. With growing domestic demand, Indonesia could turn into a net oil importer by the end of the decade. More than 20 GWe of new capacity are expected to be installed in Indonesia before 2003; however, under the current national limits on coal consumption (40 million tonnes per year), the maximum coal-fired capacity would be limited to 15 GWe. The government's studies have shown that a nuclear power programme would be feasible, although nuclear generated electricity would not be the cheapest option right now.

Environmental protection. Fossil fuels are the main energy source for electricity generation in Asia. China and India, the region's two biggest coal users, will continue to get the bulk of their power needs from coal. The burning of fossil fuel leads to quite large emissions of carbon dioxide, and sulphur and nitrogen oxides. China, Japan and India are among the world's major CO_2 emitting countries, ranking within the top-five in absolute terms. Asia's carbon dioxide emissions are estimated to increase by up to 30% until the year 2000. The releases of sulphur and nitrogen oxides have been causing serious pollution and significant damage to economic development and human health in the region. It is imperative to gradually reduce the share of fossil fuels and to adopt clean technologies for power generation

Transportation and transmission. The abundant coal reserves in both China and India are unevenly distributed geographically. Most of the fast developing areas, where consumption is concentrated, are far away from coal deposits. Even though about 40% of the total rail cargo capacity is taken up for coal transportation in China, the transportation network does not meet the demand. Insufficient capacity for coal transportation has become a bottleneck for economic development in the country's coastal areas.

Losses in transmission and distribution of electricity have significantly aggravated power shortages in Asian countries. In Pakistan, for example, 28% of the total electricity production is lost in transmission and distribution. Indian utilities suffered losses of about 23% during 1989-90. Long-distance electricity transmission from hydropower or pithead coal-fired power plants faces difficulties.

Financing. It is estimated that an additional power capacity of about 200 GWe is needed in Asia over the next decade. This calls for an investment of at least US $500 billion in power systems. Because most power projects in Asian countries have been domestically regulated, the governments are increasingly recognizing that they can no longer afford to foot the bill themselves. As a result, a number of Asian countries, such as the Philippines and Malaysia, are promoting privatization within the energy sector, and encouraging the private sector to invest in power projects. Direct foreign investment and joint venture schemes are other financing approaches pursued by some governments (e.g., China) to get foreign capital for large-scale and advanced power projects.*

Nuclear power experience in Asia

In Asia, 70 nuclear power plants were connected to electric grids and 21 were under construction at the end of 1992. All four of the power

*The features and problems concerning the financing of nuclear power projects in developing countries are discussed in greater detail in the IAEA's recent publication, *Financing Arrangements for Nuclear Power Projects in Developing Countries*, Vienna (1993).

reactors which started construction in the world during 1991-92 are located in Japan and the Republic of Korea. Moreover, all new reactors (more than 10) that are expected to start construction worldwide during 1993 are located in Asia. *(See table.)*

The development of nuclear power in Asian countries and regions can be grouped as follows:

- The first group includes Japan, the Republic of Korea and Taiwan, China. In order to ensure energy security and reduce dependence on imported fossil fuels, long-term consistent nuclear power programmes were established and have been successfully implemented there. In Japan, Republic of Korea, and Taiwan, China, the nuclear shares of total electricity generation reached 27.7%, 43.2% and 35.4% in 1992, respectively. To a significant degree, the industrial infrastructures have been built up and there is a growing technological self-reliance in the field of nuclear power. In Korea, the degree of technological self-reliance is expected to reach 95% by the time Yonggwang units 3 and 4 start commercial operation in 1995. On economic grounds, studies show that the use of nuclear power for electricity generation is cheaper than using fossil fuels in Japan and is competitive with coal in Korea.
- China and India form the second group. The rapid population growth and economic development call for significant expansion of electrical generation capacity. Heavy dependence on coal-fired power generation results in serious environmental pollution in many areas. Nuclear power has been introduced in order to abate the impacts and mitigate power shortages. Both countries have established capabilities in the nuclear field based on indigenous technology and resources, and they have the strong potential for further nuclear power development. Studies made in these countries show that nuclear power would be competitive in the industrial regions, which are far away from cheap coal reserves and now burdened by environmental pollution. India's tenth power plant, Kakrapar-1, has gone into commercial operation. Most Indian reactors are pressurized heavy water reactors (PHWR) of domestic design. China's first indigenous nuclear power plant (Qinshan) achieved full operation in August 1992. The first unit of the imported Daya Bay nuclear plant started up in July 1993 and the second unit is expected to start up in 1994. Nuclear projects are planned for several provinces of China.
- The third group includes the Philippines, Pakistan, and Iran. Each has had difficult experiences in the establishment of nuclear power programmes. Pakistan has a 125-MWe PHWR, which is over 20 years old and has had rather low operating performance. The Bataan nuclear power plant (a 620-MWe pressurized water reactor) in the Philippines was completed in 1986, but the government has declared that it will not be put into operation. The construction of a nuclear power plant in Iran has been stranded for a long time. The three countries, however, have not abandoned the pursuit of their commitment to nuclear power deployment. Construction work on Pakistan's second nuclear power plant (a 300-MWe pressurized water reactor supplied by China) started in August 1993. Iran is negotiating with China and Russia to buy nuclear power plants. In July 1993 the President of the Philippines ordered the formulation of a comprehensive nuclear power programme.
- The fourth group consists of a number of Asian countries, including Indonesia, Thailand, Malaysia, Democratic People's Republic of Korea, Viet Nam, Turkey, and Bangladesh. The governments all have announced their intentions to develop nuclear power. In Indonesia, a feasibility study for a 600-MWe nuclear plant in the densely populated and fast developing region of Java is expected to be completed in 1996. The aim is towards the operation of Indonesia's first nuclear power plant by 2003. In Thailand, a tentative plan to construct 6 GWe of nuclear capacity with six units is expected to be submitted for government approval and a 3-year commercial feasibility study is foreseen; the first two units are scheduled to be commissioned in 2006. In Turkey, Atomic Energy of Canada Limited (AECL) has submitted a comprehensive proposal to the Turkish authorities for a 700 MWe reactor at the Akkuyu site.

Nuclear power prospects

Planning of nuclear power projects. Ambitious plans for significantly increasing nuclear power capacity are evident throughout most of Asia. The latest orders for nuclear power plants in the world all came from Asian countries.

In Japan, nuclear energy has become an economical and stable energy source, and its role has been clearly defined for the long term. Japan's electric utilities have announced a plan for starting construction on 10 new nuclear units within the next 2 years. A report by the Ministry of Trade and Industry has called for an additional 40 GWe to be added by 2010, doubling Japan's present nuclear capacity.

The Republic of Korea is planning to build 18 more nuclear units over the 1991-2006 timeframe, with the total nuclear generating capacity scheduled to reach 23 GWe by the year 2006.

Nuclear power status in Asia at the end of 1992

Country	Reactors in operation: No. of units	Reactors in operation: Total MWe	Reactors under construction: No. of units	Reactors under construction: Total MWe	Nuclear share of electricity (%)	Reactors planned: No. of units	Reactors planned: Total MWe	Reactors planned: Year in operation
China	1	288	2	1812	0.1	12	8400	2005
India	9	1593	5	1010	3 3	16	3100	2000
Indonesia						1	600	2003
Iran			2	2392			600-2600	2010
Japan	44	34 238	9	8129	27 7		72 500	2010
Korea Rep. of	9	7220	3	2550	43 2	27	23 000	2006
Malaysia						1		2002
Pakistan	1	125			1.2	2	425	1999
Philippines			1	620**			620-1500	2010
Thailand						2	2000	2006
Turkey						1	700	2000
Viet Nam							800-1200	2010
*Asia total**	70	48 354	22	16 513				
World total	424	330 651	72	59 720	16.7			

*The totals includes 6 units, 4890 MWe in operation, in Taiwan, China (nuclear share 35 4% of total electricity generation)
**Mothballed plant
Sources IAEA PRIS Information for planned reactors was derived from selected reports on national plans

In China, nuclear power is clearly gaining in importance in the national energy development strategy. Up to now eight provinces have been active in constructing plants or in site and feasibility studies for new nuclear plants. The review of the preliminary design for the second phase of the Qinshan project (two 600-MWe pressurized water reactors) was approved in November 1992. Preparations and negotiations with foreign suppliers have begun for the second phase of the Daya Bay project (two 900-MWe pressurized water reactors). An agreement was signed by China and Russia for construction of two units of WWER design (two 1000-MWe plants) in Liaoning. Additionally, Jiangxi province is preparing to build a 600-MWe nuclear plant, and Hainan Island has proposed to build two 350-MWe pressurized water reactors.

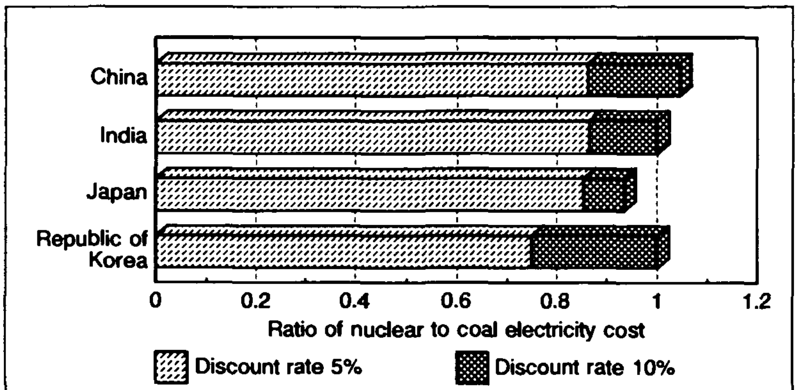
In Taiwan, China, Taipower has invited bids for its fourth nuclear power plant (two 1000-MWe light water reactors). The plant is expected to be completed by the year 2000.

India plans to build as many as 15 more nuclear power reactors in the next 10 years to ease the power crisis in the country. If budgetary resources are available, Pakistan intends to buy a second 300-MWe pressurized-water reactor from China. In its long-term planning, Indonesia has stated its intention to start a nuclear power programe, while in Thailand, 6 GWe of nuclear capacity has been proposed.

Economic competitiveness. The economic competitiveness of nuclear power with conventional baseload electricity generation depends on a number of country-specific and local factors. These include the local prices of fuels, environmental protection and other regulatory requirements, and the required capital return rate or discount rate.

Nuclear power is competitive with conventional electricity generation in countries with strong electric grids and lack of indigenous energy resources, such as Japan and the Republic of Korea. Nuclear power is also competitive in regions with strong economic growth which are distant from large coal or gas fields or cheap hydropower. This includes the coastal regions of China, West and South India, and some regions of the third and fourth groups of countries

Economic competitiveness of nuclear and coal-based electricity in Asian countries



Notes: Assumptions include a projected plant lifetime of 30 years and a load factor of 75%.
Source: Joint study of the IAEA and the Nuclear Energy Agency and International Energy Agency of the Organization for Economic Co-operation and Development (1993).

referred to above. Studies made by four Asian countries (China, India, Japan, and the Republic of Korea) have shown that nuclear power would be, in most cases, the cheapest option for generating electricity from projected plants which are scheduled to start operation around the year 2000.

Technology development. Nuclear power developments in Asian countries are promoting the technological development of national nuclear industries. The world's first advanced boiling water reactor is being built in Japan. Significant development of Candu PHWRs will be gained by replication in the Republic of Korea. China is developing an indigenous reference plant, the AC 600-MWe PWR, characterized by advanced functions and passive safety features. India is considering the utilization of thorium for nuclear electricity production because of its limited uranium resources. Due to their small electric grid systems and the limited availability of capital, many Asian countries also are attractive markets for deployment of improved small and medium power reactors.

Fast breeder reactors (FBRs) are being actively developed in Asia, with an eye towards nuclear's long-term contribution. At Monju, Japan's pilot fast breeder reactor, first criticality is expected to be achieved in 1994. India plans to make a detailed review and finalize the design of a 500-MWe prototype fast breeder reactor in the next 2 years. The engineering preparation for a pool-type experimental FBR (65 MWth) has been implemented in China.

Addressing issues and needs

The high capital costs of nuclear power make it difficult to implement ambitious plans for nuclear power in many developing countries which lack investment capital. Financing is a key factor for expanding nuclear power in China and India. A number of Asian countries are trying to attract private and foreign investment in nuclear power plants.

The extent of national participation is dependent on the locally available industrial infrastructure. A strong participation of local industry may lead to initially higher costs for a small-scale nuclear programme, but could lead to lower costs for a long-term, large-scale nuclear power programme.

Nuclear power deployment is technologically demanding in terms of human resources. Highly qualified staff are vital for design, equipment fabrication, construction, management, and operation of nuclear power plants in order to achieve good plant performance, high levels of safety, and competitive economics. Other factors for consideration include the selection of suitable sites for power plants and the permanent disposal of radioactive waste, two areas which have raised public concern about nuclear energy.

The IAEA offers comprehensive assistance to support countries interested in electric system expansion planning, nuclear power project feasibility studies, plant siting, human resources development, project management, plant engineering, and safety assessments, for example. Various technical assistance projects have been carried out for Asian nuclear power development.

Throughout this decade, Asia is expected to continue its rapid economic growth with increasing demand for electricity. Nuclear power could play an increasingly important role in sustainable economic development in the region, providing particular benefits in areas of environmental protection and energy security. It is estimated that as many as 90 to 100 nuclear units could be connected to Asian grids by the year 2000, with further development of nuclear power foreseen after the turn of the century. ❐

A technician working on a power transmission line in Bangladesh. ***(Credit: ADB)***

Regional co-operation in Asia and the Pacific: Energy, electricity, and nuclear power planning

Through an IAEA technical co-operation programme, countries are acquiring experience in analyzing their energy options

by J. Easey and P. Molina

Over the past 5 years, countries in the Asia and Pacific region have been working together through an IAEA co-operative programme to study their energy futures. The work has been done through a series of workshops and training courses arranged under the Regional Co-operative Agreement (RCA) for Research, Development, and Training Related to Nuclear Science and Technology, which was first launched in 1972. Since then, 15 countries in the Asia and Pacific region — Australia, Bangladesh, China, India, Indonesia, Japan, Republic of Korea, Malaysia, Mongolia, Pakistan, Philippines, Singapore, Sri Lanka, Thailand and Viet Nam — have become RCA members.

Over the past decades, an extensive range of RCA activities has been implemented, mainly in the fields of agriculture, industry, medicine, radiation protection, and basic nuclear science. In 1987, the programme's scope was enlarged by the initiation of the project on energy and nuclear power planning. Its principal focus was to build national experience in the use of two energy and nuclear power planning models, namely the Model for Analysis of Energy Demand (MAED) and the Wien Automatic System Planning Package (WASP). The project, originally set up for a duration of 4 years, was effectively carried out through 1992. In July 1993, national participants in the project, meeting in Jakarta, recommended its extension.

This article reviews activities under the RCA energy project, and reports on the recommended course of action for the project's next phase.

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Economic and energy background

Over the last decade, RCA countries, along with some others in the Asia and Pacific region, have experienced rapid economic growth that largely surpasses that of other regions in the world. This has translated into improved standards of living and, quite naturally, a rise in the demand for products and services. These and other aspects have contributed to increased demand for energy in general and electricity in particular throughout the region, with some countries having very high annual growth rates.

While the figures give an impressive indication of the economic performance of RCA countries, these results need to be considered with indices expressed on a *per capita* basis. *(See tables.)* Wide disparities can then be seen between some RCA countries. Their *per capita* gross domestic product (GDP) varies from about US $130 (constant 1980 US dollars) for Viet Nam to around US $13 000 for Australia and Japan.

Similarly, *per capita* energy consumption in 1991 varied widely among RCA countries. The upper range was represented by Singapore, where *per capita* consumtion was 6667 kilograms of oil equivalent (kgoe) and Australia, where it was 5033.5 kgoe. At the other end of the spectrum were Bangladesh, with 77.4 kgoe and Viet Nam, with 148.4 kgoe. The average for RCA countries in 1991 was about 676 kgoe. This was less than half the world average, which was about 1583 kgoe in 1991.

Per capita electricity production in 1991 for RCA countries also followed a wide range. At the upper end were Australia (8533 kWh) and Japan (7129 kWh), while at the lower end were Bangladesh (67.1 kWh) and Viet Nam (120 kWh). It is of interest to note the high levels attained by countries like Singapore (5725.4

kWh) and Mongolia (1291.7 kWh). Nevertheless, the average *per capita* electricity consumption for RCA countries was 817.4 kWh, compared with the world average of 2195 kWh in 1991.

One possible explanation for the impressive economic growth in Asia lies in current patterns of trade within the region. Regional trade is becoming steadily more important and is expected to surpass trade with other regions of the world in the future. This will make the region more self-reliant. Economic growth in Asia is projected to continue for some years to come and this will have a great impact on the demand for energy in general and electricity in particular.

Economic development alone will force an increase in energy required to produce the goods and services expected to fuel development in the export sector. At the same time, greater demand for energy will be needed to satisfy domestic needs of the population.

Electricity's share of total energy demand is expected to increase throughout the region. Such has been the case in industrialized countries. In Asia, many countries are going through an industrialization process which will bring the installation of new, modern factories that use electricity more intensively. Additionally, the rate of electrification will increase attempts to bring services to all non-electrified villages. In turn, *per capita* energy consumption will tend to go up as the population requires more household appliances that use electricity.

From the supply side, it is recognized that the region has sufficient energy reserves to support the expected demand. Nevertheless, there are some complications. Firstly, resources are not evenly distributed within the region and not even within the countries where they are located. In addition, in many cases the principal centres of energy demand are located far away from the reserves. The problem is compounded in countries with specific geographical conditions (insular), or which lack adequate transportation infrastructures.

Such factors illustrate the need for careful planning of future facilities for energy and electricity production.

To date, countries in the region have made strong efforts to plan their energy and electricity systems. However, the efforts will have to be intensified in the future as primary energy resources become scarcer and demand continues to increase. In addition, investments in the energy/electricity sector will be highly competitive with other investments required for overall socio-economic development in areas of health care and education, for example. Furthermore, adequately balancing the energy supply/demand equation has become more complex with growing consideration of environmental issues.

In the case of electricity, all electricity production chains will have to be carefully assessed, primarily because of electricity's rising projected share of total energy. Systems based

Average annual growth rates for RCA member countries (1980-91)

Data in per cent	Population	GDP 1980-90	Energy consumption	Electricity production
Australia	1.52	3.21	2.08	4.00
Bangladesh	2.56	3.45	5.95	11.60
China	1.48	8.73	4.49	7.63
India	2.07	5.74	5.09	9.74
Indonesia	2.00	4.70	3.94	11.28
Japan	0.55	4.25	2.30	4.41
Rep. of Korea	1.27	8.71	6 56	11.78
Malaysia	2.65	5 95	7 40	9.96
Mongolia	2.78	6.05	2.49	7.59
Pakistan	3.27	6.15	6.33	11.21
Philippines	2.49	1.72	2.04	1.98
Singapore	1.15	6.98	4 88	8.31
Sri Lanka	1.49	4 25	2 76	6.66
Thailand	1.56	7.49	5.75	12.03
Viet Nam	2.18	4.54	0.19	6.89
Average for RCA countries	1.80	5.33	3.97	6.53

Per capita gross domestic product (GDP), energy consumption, and electricity production in RCA member countries

	Per capita GDP (1980 US $)		Per capita energy consumption (kg oil equivalent)		Per capita electricity production (kWh)	
	1980	**1990**	**1980**	**1991**	**1980**	**1991**
Australia	10 674	12 595	4 735	5 033	6 542	8 533
Bangladesh	171	186	54	774	29	73
China	293	584	473	652	288	549
India	251	356	239	329	161	358
Indonesia	517	670	422	519	90	233
Japan	9 068	13 006	2 953	3 573	4 708	7 129
Rep. of Korea	1 637	3 318	1 156	2 024	997	2 956
Malaysia	1 779	2 439	760	1 252	697	1 486
Mongolia	835	1 142	1 424	1 380	781	1 292
Pakistan	328	431	222	306	172	389
Philippines	724	669	457	435	356	337
Singapore	4 853	8 494	4 478	6 667	2 700	5 725
Sri Lanka	279	364	242	278	111	192
Thailand	688	1 211	522	813	310	913
Viet Nam	105	132	184	148	73	120
Average for RCA countries	842	1 183	536	676	496	817

Note Data are rounded

Power reactors in RCA member countries

	Power reactors				Nuclear production/share of total electricity		Operating experience	
	In operation		Under construction					
	No. of units	Capacity MWe net	No. of units	Capacity MWe net	TWh electric	% of total	Years	Months
World total	424	330 651	72	59 720	2027.4	16.7	6479	9
RCA members:								
China	1	288	2	1 812	0 5	0.1	1	1
India	9	1 593	5	1 010	5.6	3.3	101	3
Japan	44	34 238	9	8 129	217 0	27.7	556	11
Korea, Rep. of	9	7 220	3	2 520	56.5	43.2	72	1
Pakistan	1	125	0	0	0.5	1.2	21	3
Total RCA	64	43 464	19	13 191	280.1	17.2	752	7
Per cent of world total	15 1	13.1	26.4	22.6	13 8		11.6	

on the burning of fossil fuel particularly would need to be assessed in terms of their environmental impacts. Renewable energy sources and nuclear power, although accepted to be generally more benign to the environment, would have to be assessed in terms of their industrial requirements and the fuels needed for manufacturing and construction of the plant, processing or fabrication of the fuel, and disposing of the wastes. These comparative assessments not only will have to look at the fuel being burned in a plant, but at all aspects related to the fuel's use in the plant, whose construction itself will have to be addressed. In this respect, a nuclear power plant shows the advantage of having practically no atmospheric emissions compared to a fossil-fuelled plant. However, concerns still exist with regard to the disposition of the spent nuclear fuel.

Currently the demand for electricity in RCA countries is largely met by hydrocarbons and this trend will continue in the future. At present, nuclear power accounts for about 10% of the total electricity capacity of the region and close to 12% of the total electricity generation. This is largely due to the installed nuclear capacity in Japan and Republic of Korea. *(See table.)* Only five RCA countries have nuclear power reactors in operation (China, India, Japan, Republic of Korea, and Pakistan). At the end of 1992, these countries had 64 power reactors in operation with a combined capacity of 43 464 MWe (net), altogether representing about 13% of the total nuclear capacity worldwide. The same countries have 19 power reactors under construction with a combined capacity of 13 191 MWe (net). If brought on line as scheduled, these plants will increase the RCA group's share of worldwide nuclear capacity to about 15% by the year 2000.

Beyond 2000, this share is expected to increase further from the introduction of nuclear power in some other countries. Indonesia, for example, is undertaking a feasibility study for a nuclear power project targeted for operation by

Estimates of world energy, electricity, and nuclear power consumption

Country Group	1992			2000 (estimated range)			2010 (estimated range)		
	Total energy use (EJ)	Electricity share (%)	Nuclear's electricity share (%)	Total energy use (EJ)	Electricity share (%)	Nuclear's electricity share (%)	Total energy use (EJ)	Electricity share (%)	Nuclear's electricity share (%)
North America	92.1	38.2	7 3	94 - 95	40 - 43	7.2 - 7.3	95 - 99	43 - 50	7.3 - 7.4
Latin America	23.7	27.5	0.5	30 - 32	30 - 31	1.0 - 1.1	40 - 45	35 - 36	1 0 - 1.2
Western Europe	60.2	38.8	11 9	63 - 64	42 - 43	12	66 - 68	47 - 50	10 - 13
Eastern Europe	70.9	29.2	3.5	72 - 73	32 - 34	4.3 - 5.1	73 - 76	35 - 40	5.2 - 7 5
Africa	15.5	20.8	0 6	20 - 21	21 - 22	0.5	28 - 30	22 -23	0.4 - 1 0
Middle East & South Asia	27 3	21.5	0.2	34 - 35	24	0.5 - 0.7	45 - 49	27 -28	0.5 - 0 9
South East Asia & the Pacific	13.6	24.4		17 - 18	27		23 - 25	31 - 32	0.2 - 0 8
Far East	62.7	30.6	4.7	73 - 76	33 - 34	5.8 - 6 5	90 - 98	35 - 38	6 1 - 7 8
World Total	366.0	32.1	5.3	403 - 414	34 - 35	5.5 - 5.8	460 - 490	37 - 40	5 2 - 6.4

Source IAEA Reference Data Series 1 (July 1993) the year 2005. Similar studies are expected to be undertaken by other countries. *(See related article in this edition beginning on page 2.)*

Based on existing trends, nuclear power is likely to make an important contribution to the future development of RCA countries. Careful planning, however, will be needed concerning both the construction of plants and, later, their safe operation. This calls for timely decisions in both areas. The planning takes on greater importance for the introduction of the first nuclear power reactor into the electrical grid of a country.

The RCA energy planning project

In 1987, approval was given for a project on Energy and Nuclear Power Planning (ENPP) as part of the RCA programme.

The project's basic aim was to promote regional co-operation in energy and nuclear power planning by focusing on experience acquired by RCA countries in the use of the IAEA's computer models, known as MAED and WASP. Workshops, training courses, and other activities were organized for this purpose.

Workshops. The first workshop was held in Jakarta, Indonesia, 7-11 December 1987, and dealt basically with the WASP model. Its basic objective was the exchange of information and experience among countries in the use of the WASP methodology for planning expansions to electric systems, including nuclear power planning. A second objective of the meeting was to consider whether improvements were needed to the WASP program for better adaptation to the needs of countries in the region.

Three similar workshops followed: in Kuala Lumpur, Malaysia, 5-9 December 1988, which incorporated the MAED as well as WASP methodology; and in Beijing, China, 4-8 September 1989; and Daejon, Republic of Korea, 27-31 August 1990. The last two workshops additionally incorporated discussions on the importance of environmental issues with respect to energy and electricity planning.

Each workshop featured national presentations by participants that reviewed the status of energy, electricity, and nuclear power in their countries. This enabled the exchange of factual data and offered participants the opportunity to jointly identify major problems and formulate recommended courses of action. The MAED and WASP planning models were recognized to be very powerful tools for energy and electricity planning, and participants recommended the organization of regional training courses to provide specialized training for experts from the region.

Training courses. Two sets of regional training courses were arranged under the RCA project.

One set, following the recommendations made at the workshops, was organized on the subject of planning for electric system expansion. The first course was held at the Asian and Pacific Development Centre (APDC) in Kuala Lumpur, Malaysia; it was hosted by the Government of Malaysia, co-hosted by the APDC, and co-sponsored financially by the Asian Development Bank (ADB). Support was also obtained from the World Bank (IBRD) and the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). The second course was held at the Water and Power Development Authority (WAPDA) in Lahore, Pakistan; it was hosted by the Government of Pakistan through WAPDA and the Atomic Energy Commission of Pakistan, and co-sponsored financially by the ADB. Other support was provided by ESCAP, and by the Government of Canada through a project of the Canadian International Development Agency (CIDA) that is being carried out by ACRES International Ltd. for Pakistan.

These courses principally emphasized the linkages between energy planning, including electricity planning, and other sectors of the economy. In particular, the participants were trained in the use of the IAEA's electric system expansion planning methodology and the computer program WASP-III in its personal computer version. In each course, teams of two or three participants from the same country carried out case studies using their national data. Lecturers for the courses came from countries in and outside the region, as well as from the ADB, ESCAP, IBRD, and IAEA. A total of 58 energy and electricity planners from 10 RCA countries received training through these courses.

Another set of regional training courses was organized under a special contribution by the Republic of Korea. This set mainly focused on nuclear power project planning and implementation. Held during 1988-91, these 3-week courses were organized by the Korea Atomic Energy Research Institute (KAERI) in Daejon and included a sequence of topical subjects based on the Korean experience. Altogether, 64 specialists, including 54 from 11 RCA member countries, participated in these training courses. Most participants had extensive experience in the field of nuclear science and technology.

The courses primarily sought to provide participants with practical skills and methods in areas of nuclear power plant management, ranging from feasibility studies and bid evaluations to commercial operation. The final course particularly focused on the development of organizational, industrial, and manpower infrastructures that are essential for embarking on a nuclear power programme.

Most course lecturers were provided by the Republic of Korea and included experts from KAERI and other Korean companies, such as Korea Power Electric Corporation, Korea Power Engineering Company, Korea Heavy Industries Construction Company, Ltd., and universities. Several rounds of discussions on specific subjects were held in each course to highlight the experience gained from different approaches for planning nuclear power programmes. Also included were visits to nuclear and related sites and practical demonstrations of technology, such as nuclear plant simulators.

Future activities of the project

In July 1993, at the Project Formulation Meeting for the RCA project on energy and nuclear power planning, participating countries explored future needs and directions. The meeting was hosted by the Government of Indonesia and organized by its National Atomic Energy Agency (BATAN) at its facilities in Pasar Jumat. Attending were National Co-ordinators from Australia, Bangladesh, China, India, Indonesia, Republic of Korea, Malaysia, Mongolia, Pakistan, Philippines, Sri Lanka, Thailand, and Viet Nam.

In reviewing the project, the National Co-ordinators agreed that the first phase had been very useful in providing experience in the WASP methodology and that it had served as an effective forum for the regional exchange of experience in energy, electricity, and nuclear power planning. They saw this investment in their analytical capabilities as requiring further exploitation nationally, through further training of key personnel using the "train-the-trainers" approach and to increase the accuracy of the results by improving the information in national databases. In addition, it was felt that this project could make a positive contribution to establishing effective strategies for nuclear power implementation.

In recommending a 5-year extension of the project, the National Co-ordinators formulated two technical objectives as the basis of future co-operation:

- To enhance and improve the reliability and quality of forecasting, planning, and analytical capabilities in the region for future energy and electricity needs and impacts.
- To facilitate national implementation of nuclear power programmes through the pooling and analysis of information on effective strategies used in RCA countries.

Through the 1990s, and into the next century, RCA countries will have to take further steps to reinforce their electricity generation capacities. The need for adequate planning is and will continue to be of tantamount importance. To assist this process of analysis and assessment, the RCA project on energy and nuclear power planning can continue to provide valuable support. ❐

Discussing plans for the Republic of Korea's first nuclear plant, Kori, back in 1974. Today nine nuclear units provide more than 40% of the country's electricity.

Energy strategies and nuclear power in Latin America and the Caribbean: Sustaining development

Expanding nuclear energy's role over the next decades could help the region meet rising demand for electricity services

by E. Bertel and P. Molina

Latin America and the Caribbean are home to 8% of the world's people who together consume about 6% of the world's primary energy production. In the coming decades, the region — like most developing parts of the world — will face increasing demand for energy, especially electricity services.

Future energy requirements will depend on a number of factors, but population growth and evolving lifestyles are likely to be major driving factors. The increase in population will lead to rising energy demand even if *per capita* energy use — which now is relatively low — remains at the present level. The process of urbanization will most likely continue, centered around huge megacities such as Mexico City, São Paulo, Rio de Janeiro, Buenos Aires, and Bogotá. This will tend to increase the demand for energy and especially for electricity; it will also create more urgent environmental problems, calling for the adoption of more efficient and environmentally sound energy policies.

Since the region's energy intensity — the energy consumption per unit of gross domestic product (GDP) — is relatively high, there is considerable potential for greater energy efficiency in both the industrial and residential sectors. Substantial savings are possible through technological progress and voluntary policies. However, the GDP composition tends to be energy intensive and structural changes will take time. Therefore, even with the implementation of energy efficiency measures and conservation programmes, the energy intensity will remain stable or continue to grow slowly. Furthermore, the improvement of energy efficiency requires investments that could be difficult to finance. Like other developing parts of the world, the region has limited financial resources and large needs for social and economic development and for repayment of previous loans.

Therefore, the region's primary energy consumption is expected to keep growing at a higher rate than the world average. Additionally, the demand for commercial energy sources will increase more rapidly since they will progressively substitute for non-commercial sources. Scenarios developed by the World Energy Council (WEC) show that the primary energy consumption of Latin America and the Caribbean will increase by a factor of 1.25 to 1.7 from 1990 to 2000, depending on economic and population growth and on the relative success of any programmes for energy efficiency and demand management. Over the period 2000 to 2015, the region's energy consumption would double according to the low scenario of WEC and triple in the high scenario. *(See table.)*

In the past, electricity demand has grown more rapidly in the region than has total primary energy demand. This trend is expected to continue because of rapid urbanization and industrialization. The region's average *per capita* electricity consumption is rather low compared to the world average. The demand for electricity services is far from reaching the saturation level in the residential sector. The electrification of rural areas will be necessary to enhance the quality of life and will add to the need for electricity generation, transmission, and distribution capacity. The structural evolution of the industrial sector is likely to favour the development of advanced technologies and modern production processes which are more

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Selected IAEA co-ordinated research programmes using nuclear techniques in health-related environmental studies

Years	No.*	Title
1984-89	14	The significance of hair mineral analysis as a means for assessing internal body burdens of environmental pollutants
1984-90	14	Human daily dietary intakes of nutritionally important trace elements as measured by nuclear and other techniques
1985-90	11	Nuclear techniques for toxic elements in foodstuffs (RCA Region)
1987-92	20	Use of nuclear and nuclear-related techniques in the study of environmental pollution associated with solid wastes
1987-92	10	Nuclear analytical techniques for the analysis of trace elements in agroindustrial products and foodstuffs (ARCAL Region)
1990-95	10	Assessment of environmental exposure to mercury in selected human populations as studied by nuclear and other techniques
1992-97	19	Applied research on air pollution using nuclear-related analytical techniques
1996-00		Assessment of environmental pollutants using radioimmunoassay and other related techniques
1995-00		Workplace monitoring and occupational health studies using nuclear and related analytical techniques
1995-00		Secondary (regional) reference materials for environmental studies **
1995-00		Environmental biomonitoring and specimen banking for developing countries **

* Number of participating countries
** Depending on availability of extra-budgetary resources.

Note: A more detailed overview of the IAEA's work in this field can be found in the Proceedings of the IAEA Symposium held in Karlsruhe, Germany, in 1992, *Applications of Isotopes and Radiation in Conservation of the Environment.* See this *IAEA Bulletin's* "Keep Abreast" section for ordering information.

timates affects 200 million people in more than 70 countries) as the snail vectors of the disease multiply in the irrigation channels. Similarly, in Kenya, the Mwea-Tebere irrigation scheme made the country self-sufficient in rice. But it brought malaria (a disease that WHO estimates affects nearly 300 million people in altogether 103 countries) to the area as migrants from the surrounding areas and mosquitoes from the lower basin of the Tana river both moved to Mwea-Tebere. In Brazil, the opening of the Amazon has led to explosive increase in leishmaniasis and malaria. The sandflies which were a component of the sylvatic cycle for leishmaniasis and the mosquito vector of malaria came into contact with immunologically ill-prepared settlers from Brazilian towns who came to the Amazon to exploit new opportunities only to find themselves becoming new targets of the disease pathogens.

In areas such as the forests of Brazil and Colombia, information is often not available on which of the several mosquito species there are vectors of human malaria. In the early 1980s, a technique was developed to help control the disease — an immunoradiometric assay (IRMA) which uses anti-sporozoite monoclonal antibody labelled with iodine-125 to bind antigens of the sporozoite (the infective stage of the malaria pathogen which is carried by mosquitoes).

The method distinguishes the sporozoites of *Plasmodium falciparum* and *P. vivax* — the two most common forms of human malaria — from those which infect primates and other animals. It thus clearly identifies the mosquito species that carries human malaria. The subsequent study of the ecology and ethology of the vector enables the formulation of cost-effective control. Consequently, a species that breeds and rests in and around houses and feeds on humans may be controlled by spraying houses with pesticides such as DDT. If the vector were a forest dwelling mosquito, however, such a strategy would be ineffective.

When used with the malaria antigen NANP, the IRMA technique will measure anti-sporozoite antibody levels in humans. This antibody arises in response to inoculation with sporozoites through mosquito bites . Because of its short half-life, the antibody reflects malaria transmission in the previous 3 to 6 months. The test can be used to compare malaria transmission intensities in different areas, and to detect changes resulting from environmental modification or the application of control measures.

Industrialization and the associated migration from rural areas to cities lead to health concerns beyond those directly related to air pollution from motor vehicles and industries. It often means that migrants are concentrated in shanty towns where overcrowding and poor sanitation can cause the escalation of diarrhoeal, mycobacterial, and other diseases.

Easy access to pharmacies in many urban centres further can lead to the abuse of curative drugs and to the emergence of drug-resistant strains of pathogens. As they move into cities, people bring with them the vectors and diseases which until then had been limited to rural regions. Thus, in some countries in Latin America, for example, Chagas disease has entered cities. The main transmission route is no longer the triatomid bug, but blood banks where the poor sell their blood together with blood-borne diseases.

Nuclear power and electricity consumption in Latin America and the Caribbean

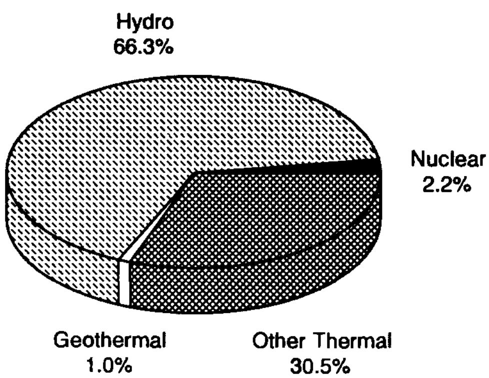
Argentina. Two nuclear units are in operation, at Atucha and Embalse; both are pressurized heavy water reactors (PHWRs). Atucha, which has a capacity of 350 MWe, was connected to the grid in 1974. The 650-MWe Embalse plant started commercial operation in 1984. Both units are operated by Argentina's nuclear energy commission (CNEA) and were imported from Germany and Canada, respectively. In 1992, the Argentine nuclear power plants provided 14% of the electricity supply of the country with a production of 6.6 TWh. A third unit is under construction on the Atucha site. Known as Atucha-2, the 600-MWe PHWR was imported from Germany and is expected to be in commercial operation in early 1995.

Brazil. One unit, Angra-1, is in operation, a 630-MWe pressurized water reactor (PWR) imported from the USA. It supplied less than 1% of the electricity consumed in the country in 1992. The second unit, Angra-2, is a 1250-MWe PWR imported from Germany. It is under construction and expected to start commercial operation in the late 1990s.

Mexico. The first unit of Laguna-Verde, a 650-MWe boiling water reactor (BWR) imported from the USA, started commercial operation in 1990. In 1992, it provided nearly 4% of the electricity supply of the country with a production of 4 TWh. The second unit, of the same type and at the same site, is under construction and expected to start commercial operation in 1994.

Cuba. Two 400-MWe pressurized water reactors (WWER-440 reactors) imported from the former Soviet Union have been under construction since the mid-1980s and are expected to be in commercial operation in the mid-1990s.

Electricity consumption



Source: EnergyStatistics, OLADE, SIEE, Version No. 4, July 1992.

hydro locations to consumers in industrial and urban areas. Moreover, hydropower is highly capital intensive and its financing may be difficult in most countries of the region.

Fossil-fuelled power plants, using coal or gas, are well-established and economically competitive technologies. Rising concern about environmental impacts of burning fossil fuels has led to the development of advanced pollution-control technologies that improve efficiency, thus reducing carbon dioxide and other emissions per unit of electricity generated. Substantial progress has been achieved. These advanced technologies are already used in some Latin American countries and could be further deployed regionally, if they are given high priority.

Geothermal energy supplies 1% of the electricity in Latin America and the Caribbean. Biomass could be a promising source of supply in the future. Although its potential for electricity generation is limited, and the environmental impacts associated with burning organic compounds are far from being negligible, this option could be of significance in the region. This is especially the case in rural areas and in large cities where it could hold ancillary benefits, such as helping the sustainable management and disposal of urban waste. The other renewable sources, such as photovoltaics or wind power, are not expected to make a substantial contribution to the region's electricity supply within the next two decades. This is because they still require considerable development efforts to reach the stage of commercial demonstration and economic competitiveness.

Nuclear power provides some 2% of the region's electricity supply. The technology is still in an early stage of development there. Only four countries — Argentina, Brazil, Cuba, and Mexico — have nuclear power plants in operation or under construction. *(See box.)*

Uranium production in Latin America and the Caribbean remains rather small, due to the prevailing conditions of the uranium market. Only two countries, Argentina and Brazil, are continuing to exploit their resources. However, the region's known and undiscovered resources are substantial, and more than 10 countries there have ongoing exploration programmes.

Argentina, Brazil, and Mexico have developed some activities in the nuclear fuel cycle industry. These mainly include uranium mining and ore processing, conversion and fuel fabrication, enrichment services, and heavy water production. This existing industrial infrastructure, together with efforts made in other areas of nuclear research and science, could serve as a basis for further deployment of nuclear power as a domestic energy source in the region.

Nuclear power prospects

Worldwide, nuclear power is the most likely non-fossil source of energy which can be deployed on a large scale and which is competitive for baseload electricity generation. Nuclear generated electricity is competitive and its relative competitiveness will increase when the environmental price tag is included in the cost of fossil-fuelled generation of electricity.

However, nuclear power is a demanding technology which has been developed mainly in industrialized countries, although a number of developing countries are already operating nuclear power plants and are planning to implement nuclear programmes. Issues of safety and radioactive waste management raise concerns that have to be addressed and public acceptance is a prerequisite for the implementation of sound nuclear power programmes. Designers are developing advanced reactors, building upon the extensive experience accumulated through the operation of the reactors of the present generation. Moreover, there is no doubt that the new generation of nuclear power plants will be better adapted to the requirements of developing countries, e.g. smaller size and easier operating and maintenance procedures.

In Latin America and the Caribbean, a broader development of nuclear power would contribute to enhancing the security of energy supply, developing advanced technologies, and implementing more environmentally benign electricity supply strategies. Since natural uranium and fuel-cycle services could be produced in the region, the development of nuclear power would allow the region to maintain its exports of fossil fuels and to diversify its energy supply using domestic resources.

Developing the industrial infrastructure for a nuclear programme involves the strengthening of a number of industries in the country to achieve maximum domestic participation. They include industries for construction, fabrication of equipment, and material and service supply. While some imports and transfer of technology will be required, the implementation of nuclear programmes in Latin America and the Caribbean would benefit from the know-how and experience already acquired there.

The advantages of nuclear energy with regard to environmental impacts would be significant for Latin America and the Caribbean, especially in densely populated areas where atmospheric pollution raises concerns. It is expected that increased efficiency in electricity supply, transportation, distribution, and end use will play a major role in environmentally benign energy strategies in the region. The development of renewable sources will also be very important, especially in rural areas.

However, nuclear power could play a significant role. The latest projections made by the IAEA indicate that the total nuclear generating capacity of Latin America and the Caribbean could be multiplied by three or more by 2010, reaching some 6 to 8 gigawatts-electric (GWe). Nuclear power could then provide 2.5% to 3% of the region's electricity supply. *(See table and graph.)*

IAEA services and support

The introduction of nuclear power in a country requires a comprehensive planning and decision making process. It is based upon a series of interrelated studies covering energy supply/demand analysis, economic and financial analysis, and assessment of the infrastructures and manpower requirements and availability.

The IAEA provides information and support to its Member States for planning the introduction of nuclear power in their energy supply system when it constitutes a viable option. In the assessment, the specific social and economic conditions of the country are taken into account.

The IAEA has developed and made available methodologies and computerized tools, and offers assistance to interested Member States for conducting studies. The studies range from the pre-feasibility stage with an analysis of the overall viability of the nuclear option, to the detailed feasibility study of the nuclear programme, and finally to the planning and implementation of the nuclear power plants. The models include MAED (Model for Analysis of Energy Demand); WASP (Wien Automatic System Planning package); VALORAGUA, specifically designed for systems with a large share of hydropower; FINPLAN, which analyzes the financial aspects of power expansion programmes; and ENPEP (Energy and Power Evaluation Programme), which offers an integrated approach to energy and electricity planning, addressing health and environmental impacts. In connection with making the models available to its Member States, the IAEA provides extensive training in the use of these tools to specialists from national organizations. Assistance for carrying out feasibility studies, bid evaluations, and financial analyses also is provided. Participation of specialists from Latin America and the Caribbean in the IAEA training programmes and technical assistance projects has enhanced the expertise available in the region for nuclear power planning. *(See table.)*

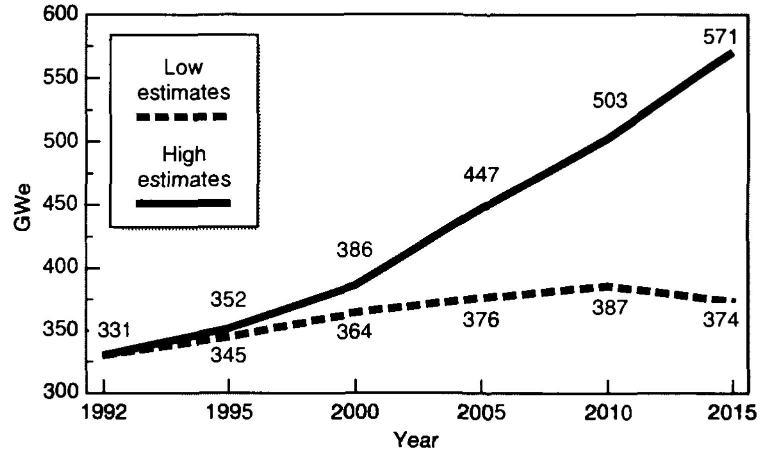
The methodologies and models developed by the IAEA have been transferred to several countries in the Latin American region. To date, 18 countries in Latin America and the Caribbean have received the WASP model; six have received the ENPEP model; three have received MAED; and three have received VALORAGUA. The models also are used by the Inter-American Development Bank (IDB) and the Latin American Energy Organization (OLADE).

National regulatory authorities are responsible for making the safety assessment of nuclear power plants and fuel-cycle facilities. For the purpose of enhancing the safety of nuclear facilities worldwide, the IAEA has initiated a number of studies and is providing services upon request to support the actions of national regulatory authorities. The IAEA's standards, guides, and practices on safety of nuclear power plants provide recommendations for national regulation and serve as a frame of reference for safety analysis, reviews, and assessment. Training programmes are provided by the Agency on safety issues to upgrade the personnel capabilities in this regard.

Need for co-ordinated efforts

Nuclear power already has contributed substantially to environmentally sound energy strategies over the past decades, and it has the potential to contribute a greater share to the electricity supply mix. Opportunities for further development exist in Latin America and the Caribbean, where environmental concerns are increasing and where natural resources and industrial infrastructure would allow a larger deployment of nuclear power. Comprehensive analyses of different energy sources for electricity generation indicate that nuclear energy is one of the most environmentally benign forms of energy, even significantly better than hydropower and other renewable sources.

In the Latin American region, nuclear power could play a role in sustainable energy strategies, based on comprehensive comparative assessment of different options that incorporate health



Source: IAEA Reference Data Series 1, July 1993

Projections of nuclear power capacity

Year	North America	Latin America	Western Europe	Eastern Europe	Africa	Middle East & South Asia	SE Asia & the Pacific	Far East	World total
1992	113.6	2.2	120.7	43.9	1.8	1.7	0	46.6	330.7
1995	115.7	2.9	122.2	51.3	1.8	1.9	0	55.7	351.6
	115.7	2.9	122.0	46.7	1.8	1.9	0	54.1	345.2
2000	118.1	5.6	128.8	56.4	1.8	3.7	0	71.1	385.6
	116.9	4.8	126.2	48.9	1.8	2.7	0	62.8	364.1
2005	121.1	7.6	138.2	79.6	1.8	5.0	0.6	93.5	447.3
	119.9	4.5	122.6	52.1	1.8	2.9	0	72.5	376.3
2010	122.0	8.2	154.0	89.5	5.0	7.5	3.2	113.4	502.9
	117.9	6.4	116.0	59.6	1.8	3.7	0.6	80.9	387.0
2015	147.1	10.5	167.8	100.8	5.0	8.2	4.4	126.7	570.6
	119.3	7.1	97.7	53.9	0	5.7	.1.2	88.9	373 8

Note Data in gigawatts. The top and bottom figures are high and low estimates respectively
Source IAEA Reference Data Series-1 (July 1993)

Interregional training course	Number of sessions	Number of participants*
Energy planning in developing countries with special emphasis on nuclear energy	8	250 (65)
Electricity demand forecasting for nuclear planning (MAED)	3	94 (21)
Electric system expansion planning (WASP)	9	227 (61)
Integrated energy and electricity planning for nuclear power development with emphasis on the ENPEP package	2	70 (24)

* Numbers in brackets indicate participants from Latin America and the Caribbean.

IAEA training courses on energy, electricity, and nuclear power planning

and environmental issues, as well as those related to security of energy supply and economic competitiveness. The region's social and economic development gives opportunities to introduce innovative policies and advanced technologies. The IAEA can continue to provide information and support to enhance the capabilities of countries for implementing a nuclear power programme when it constitutes a viable option, taking into account the specific socio-economic conditions of the country.

Nuclear's future development undoubtedly will be dependent on its social acceptability. This, in turn, will depend on its acceptance worldwide especially in industrialized countries. Although it has been demonstrated that nuclear plants are safe when properly operated, the development of advanced reactors with enhanced safety features and planned measures for ensuring safe management and disposal of radioactive waste will be key factors. The role that nuclear power can play in alleviating environmental burdens from the electricity sector is worth the joint efforts of the scientific and industrial communities to facilitate its deployment. ❐

A market square in Guatemala. *(Credit: J. Marshall, IAEA)*

Highlights of Latin American energy conference

The Energy Conference of Latin America and the Caribbean (ENERLAC '93) was held in Santafé de Bogotá, Colombia, from 15 to 18 June 1993. It was organized at the initiative of the Latin American Energy Organization (OLADE) as a response to the need for analyzing the regional energy sectors development options, within the framework of the world's geopolitical and economic environment. The Conference was hosted by the Government of Colombia, whose President, Dr Cesar Gaviria Trujillo, opened the meeting.

The Conference was divided into four main modules: world geopolitics and energy markets; economic reform and the energy sector; energy, environment and sustainable development; energy sector and private sector initiatives.

Energy supply. According to the papers presented, the region's energy supply does not raise concern about the availability of energy resources; however, large investments are required, especially in the electricity sector, to meet the demand which is expected to continue growing despite conservation and efficiency enhancement measures. The interconnection of electric and gas networks in the region will continue to be strengthened and will play a major role in enhancing the efficiency of the energy supply system.

Oil accounts for more than 50% of the region's energy supply. The region intends to remain a net oil exporter. Investments will be needed in the refining sector to increase the capacity for petroleum product production both for meeting domestic demand and to export to world markets. Gas is considered as an attractive alternative source, which is abundant in the region and could be developed on a broader scale for the regional market as well as for export worldwide. Coal contributes only marginally to the energy supply of the region; nevertheless, it is an important source in Colombia, Mexico, and Brazil and will continue to be developed with emphasis on clean coal technologies. Hydropower will remain a major contributor to electricity supply in most countries of the region. It is worth noting that biomass represents some 20% of the energy supply of the region and is expected to be developed further, using advanced technologies for processing and burning biomass products.

In several countries of the region, nuclear power is viewed as an alternative for the medium and long term; in this regard the role of the IAEA is important for assisting Member States, upon request, in their research and development activities and in assessing the viability and feasibility of nuclear programmes.

Economic factors. The ongoing economic reforms in the region, including the privatization of the energy and electricity sector, are expected to improve the technical and economic performance in production, distribution, and final use of energy. The governmental policies implemented in the past have proven to be far from the economic optimum; the tariff-setting policies, aiming in principle toward providing services affordable by all, led to insufficient earnings of the companies and lack of incentive to invest. At present, there are huge capital requirements for the energy sector which cannot be financed by the region alone.

The privatization of the energy sector, and the opening of the sector to foreign investors, should provide part of the funding for modernizing and adapting the infrastructure for producing and distributing energy, especially electricity, in the region; however, support from international development banks will also be necessary. Since private investors will design their policies in view of cost optimization, the result of the economic reform in the sector should be efficiency enhancement and improvement of natural resources management. However, concerns were expressed by some speakers regarding the willingness of the private sector to implement sustainable strategies in the long term; in particular, it was stressed that the governments should continue to play a lead role in planning and decision making in the energy sector in order to ensure a proper balance between short-term economic optimization and long-term objectives, such as energy independence and environmental protection.

Environmental considerations. There is growing interest in assessing the environmental impacts of energy strategies in Latin America and the Caribbean, like everywhere in the world. This was illustrated by the number of papers reporting studies on environmental impact monitoring, analysis of the status and trend in emissions from the energy sector, and assessment of alternative strategies for alleviating or mitigating environmental impacts. It was stressed that, while pollution problems do exist in the region, countries of Latin America and the Caribbean are among the lowest carbon dioxide emitters *per capita* in the world, essentially due to the large share of hydropower in the electricity generation mix. Conservation and demand management measures were presented as the preferred option for maintaining a low level of emissions and emphasis was put on clean fossil-fuelled technologies.

Nuclear power and its role in limiting emissions of carbon dioxide

Studies show that the use of nuclear energy is helping countries avoid emissions of CO_2 from electricity production

by
J.F. van de Vate
and
L.L. Bennett

Roughly 80% of carbon dioxide — one of the most important gases linked to what is known as the "greenhouse effect" — originates from energy production and use. This atmospheric trace gas today accounts for more than 60% of the greenhouse perturbation.

The need to limit emissions of carbon dioxide (CO_2) from the production of energy and other industrial activities has commanded more international attention in recent years. So, too, has the potential role of nuclear power — which is free of CO_2 emissions — for electricity generation, a growing component of energy production systems worldwide. Nuclear power is one of the energy sources that has contributed substantially, and could contribute even more in the future, to the lowering of greenhouse gas emissions into the atmosphere.

In June 1992, the United Nations Conference on Environment and Development (UNCED), popularly called the "Earth Summit", was held in Rio de Janeiro, Brazil. It is considered by many to be one of the major international meetings of the century. Agenda 21, one of the main outputs of the meeting's action programmes, contains a strategy which links environment and development to improve the endangered sustainability of the Earth and its inhabitants. As a follow-up to the Stockholm 1972 Conference on the Environment, though in a new era of changed threats and opportunities, emphasis at the Earth Summit was on a new, strongly emerging, environmental subject, namely climate change. Of the two topics in this problem field — stratospheric ozone depletion and the greenhouse effect — the latter one has the strongest relationship with a basic need of humanity: energy.

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It is remarkable, however, how little attention was given to nuclear energy in most of the UNCED documents. For example, Agenda 21 does not include nuclear energy in its definition of "environmentally safe and sound and cost-effective energy systems, particularly new and renewable ones" from which an increased contribution is desired. *Our Common Future*, the report of the UN World Commission on Environment and Development to the Earth Summit, was rather critical about nuclear energy and largely underlies Agenda 21.

More recently, however, a publication issued by the environmentally conscious Club of Rome took a more positive view. Called the *Second Report to the Club of Rome*, it considers nuclear energy to be an indispensable part of a greenhouse-benign energy policy. The United Nations Framework Convention on Climate Change (FCCC) — the Earth Summit's document on climate change that was unanimously adopted and has been signed by 154 countries — is neutral about the various energy sources. The FCCC is becoming a widely accepted basis for national energy strategies, i.e. to stabilize "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." As a consequence, lowering the rate of greenhouse gas emissions has become a dominant factor in energy planning, alongside existing factors such as cost-effectiveness and security of supply.

Nowadays environmental and climate change policies are affecting energy production in many parts of the world. The IAEA's programme on comparative assessment of nuclear and other energy sources aims at providing tools and data for a comprehensive and fair comparison in the context of energy planning. It is very difficult, if not impossible, to express all environmental impacts from the different energy sources in common units. This article, therefore, limits itself to the greenhouse effect. In this context, it addresses the role which nuclear power has played in lowering CO_2 emissions compared to other energy sources, as well as the future needs of low-CO_2 emitting energy sources.

The message from the past

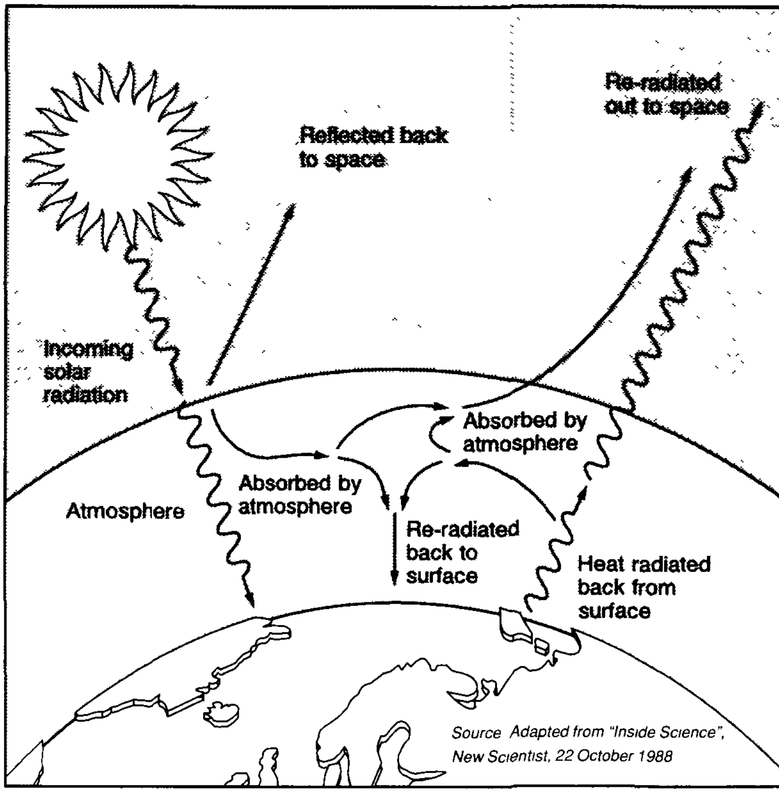
Atmospheric levels of CO_2 are increasing at a rate of about 0.4% per year. This increase is mainly due to the use of fossil energy, with associated global CO_2 emissions now estimated at about 24 000 megatonnes per year. The annual increase from the energy sector is rather constant at about 250 megatonnes CO_2 per year, mainly due to the increasing energy use by developing countries. Industrialized countries and those "in transition" have stabilized their emission rates since the mid-1970s.

Understanding this stabilization of the CO_2 emission rate could help to develop an energy strategy that is more benign to the environment. For this, a closer look at *per capita* CO_2 emissions might be useful. Such an analysis eliminates the population factor (the population growth of developing countries dominates the world population growth).

With the exception of countries in the Organization for Economic Co-operation and Development (OECD), where there was a slight decrease after 1973, *per capita* CO_2 emissions have had a general tendency to increase. *(See graphs, following pages.)* In the former Soviet Union, the increase after 1980 is rather small. Among developing countries, *per capita* CO_2 emissions show a steady increase at a rate of about 3.5% per year. Remarkable is the one order of magnitude difference in *per capita* CO_2 emissions between the industrialized and developing countries, which reflects the different standards of living and lifestyles.

We speculate that the stabilization of the *per capita* CO_2 emissions in industrialized countries is due to the penetration of energy sources having low or zero CO_2 emissions. One indication of this is the strongly increased share of electricity in energy production in industrialized countries since the mid-1970s, and the associated penetration of nuclear power in a number of countries.

However, further insight can be obtained from trends of the CO_2 emission factor. This is defined as the amount of CO_2 emitted per exajoule (EJ, or 10^{18} joule), a factor that can be compared for the different fossil fuels. For a specific country or region, the emission factor is a technological indicator of its greenhouse benignancy.



Source Adapted from "Inside Science", New Scientist, 22 October 1988

The greenhouse effect

The atmosphere functions like the glass in a greenhouse, protecting the Earth from cooling to levels far below the freezing point. However, the atmospheric levels of greenhouse gases have been increasing worldwide for more than a century. These increased greenhouse gas levels disturb the Earth's balance of incoming solar radiation and outgoing heat.

The radiative forcing of the atmosphere by anthropogenic greenhouse gases would not be dramatic if there were not an important feedback enhancement. This feedback is caused by the Earth's natural and most important greenhouse gas, namely water vapour. The humidity of the air increases when the atmosphere heats up, thereby further increasing the radiative forcing.

This process is considered to be a serious threat to humanity and to the environment, not only because of the resulting "global warming" (which some expect to be even beneficial). It additionally could lead to increased frequencies and severeness of floods, droughts, and hurricanes, which are threats more common to our daily experience and understanding. Of late, interest has been growing within the scientific community of the World Climate Programme in these extreme weather events. Altogether, most experts consider that there is sufficient reason to lower greenhouse gas emissions, in particular those from energy sources.

The need for a bundle of measures. What measures should be considered to avoid further perturbation of the greenhouse and stop the future anthropogenic climate change? An interesting study by Bert Bolin, the chairman of IPCC from its first days, answers this question. In his address in May 1989 to the IPCC Working Group III on Response Strategies, Bolin has shown that only a bundle of the strongest measures is effective in avoiding at least the greatest part of the two degrees global warming predicted for 2030.

Bolin's study reveals that, in order to avoid this two degrees of warming, one needs a complete ban of chlorofluorocarbons (CFCs) in 2000, to reforest at least half the land areas deforested since 1900, to lower the rate of fossil fuel use by 0.5% per year, and to improve the efficiency of energy end-uses significantly.

Generally, global and regional CO_2 emission factors show a continuous, relatively stable decrease. Developing countries have the lowest annual rate of decrease (-0.24 megatonnes of CO_2 per EJ), and the former Soviet bloc the highest (-0.43 megatonnes). For the world as a whole, and for OECD countries, the values are -0.29 and -0.33, respectively. These rather stable trends of worldwide improvement of energy systems with respect to their greenhouse benignancy are encouraging.

To illustrate the role of shifts in the mix of fossil fuels used in energy production, a specific CO_2 emission factor was defined as the amount of CO_2 emitted per EJ of fossil fuel used. Until the oil crisis of 1973, this specific emission factor was improving worldwide and in industrialized and developing countries alike. However, after 1973, this emission factor hardly changed at all, except for a slight decrease after 1985.

One reason why is that the year 1973 marked the end of a period of oil substitution for coal, which is more CO_2 intensive. Thereafter, there was no substantial change in the fossil fuel mix. The continued decrease of the average CO_2 emission factor has been due to other causes. After 1973, nuclear power, and to a lesser extent, hydropower, took over the role of improving the global average CO_2 emission factor. The avoidance of CO_2 emissions by the use of nuclear power increased from about 1% in 1973 to almost 7% in 1990, while that by hydropower grew from 6.5% to 8%. It is not surprising that countries with an extensive nuclear programme show strongly improved CO_2 emission factors, i.e. greenhouse-benign energy policies. Countries which implemented extensive nuclear programmes in the period 1965 to 1990 — such as Belgium, France, and Sweden — improved significantly the greenhouse benignancy of their energy strategies. They did so by reducing their CO_2 emission factors by about one or more megatonnes per EJ per year.

During the past decades the average CO_2 emission factors for the world and for the United States remained in the range of that of oil, namely 75 megatonnes of CO_2 per EJ. This further illustrates the beneficial role of nuclear power in lowering CO_2 emissions of countries like Sweden and France since the onset of their nuclear programmes in the mid-1970s. It also shows the important role of hydropower in Sweden and Norway. Furthermore, the data show the relative stability of the CO_2 emission factors in countries with large domestic energy resources such as China (coal), USA (coal and oil), and Norway (hydropower). This indicates the high priority given to security of supply, as compared to environmental sustainability, in national energy policies during the last decades.

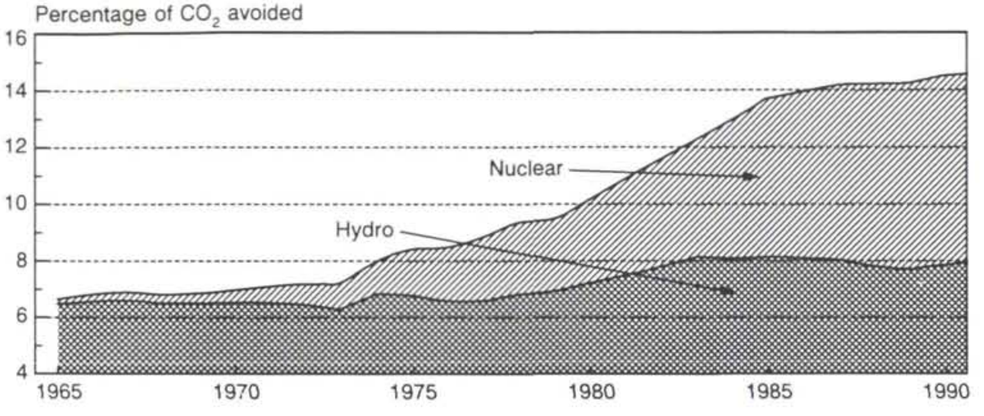
Messages from the future

There are many energy scenarios which have been developed in order to make long-term projections of energy-associated CO_2 emissions. Some of them consider nuclear energy supply explicitly. For illustrative purposes, the CO_2 emission scenarios developed by the Intergovernmental Panel on Climate Change (IPCC), International Institute for Applied System Analysis (IIASA), and World Energy Council (WEC) are analyzed below. *(See graphs.)* Also discussed are three other cases that deal with different assumptions on population growth and equitable worldwide development.

IPCC scenarios. The IPCC's reference scenario (1a) assumes that the world population will reach some 11 billion inhabitants by the year 2100 and that the average economic growth will be a reasonable 2.9% per year until 2025 and 2.3% thereafter. Natural gas and renewable energy sources, especially solar energy and biofuels which are assumed to become competitive, increase significantly their shares of total energy supply. This scenario leads to a moderate increase of energy-related CO_2 emissions.

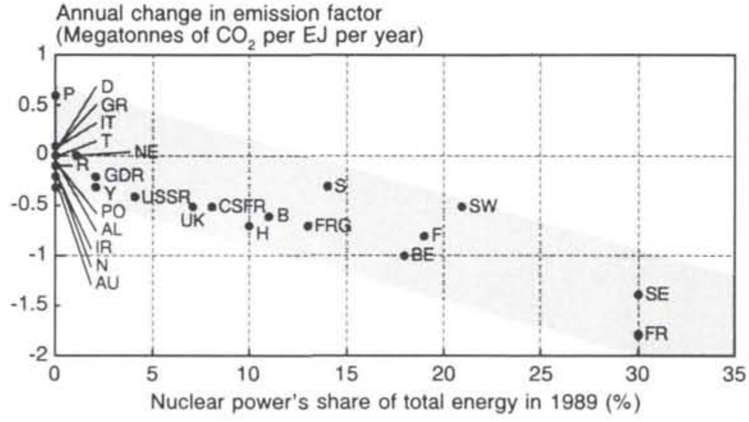
Three other IPCC scenarios hold different assumptions. Scenario-1e assumes the same population growth as the reference scenario but higher economic growth — 3.5% per year to 2025 and 3% thereafter. Natural gas is assumed to have the same development as in the reference scenario and nuclear power is assumed to be phased out by 2075. In this scenario, CO_2 emissions increase dramatically, by a factor of more than four, from 1990 to 2100. Scenarios-1c and 1d assume a lower population growth leading to 6.4 billion inhabitants in 2100; economic growth rates are also lower than in the reference scenario. Scenario-1c, which assumes the lowest rate of economic growth and a large development of nuclear power, leads to much lower long-term CO_2 emissions; they even decrease after 2025. Scenario-1d has rather stable emissions in the next century, since it assumes moderate economic and population growth rates and substantial penetration of renewable energy and to a lesser extent of nuclear power. Scenarios-1e and 1d, which show the correlation between low CO_2 emissions and a large share of nuclear power in the energy mix, illustrate the relevance of the nuclear option in implementing sustainable long-term energy strategies.

WEC scenario. The WEC Commission developed projections for energy demand to

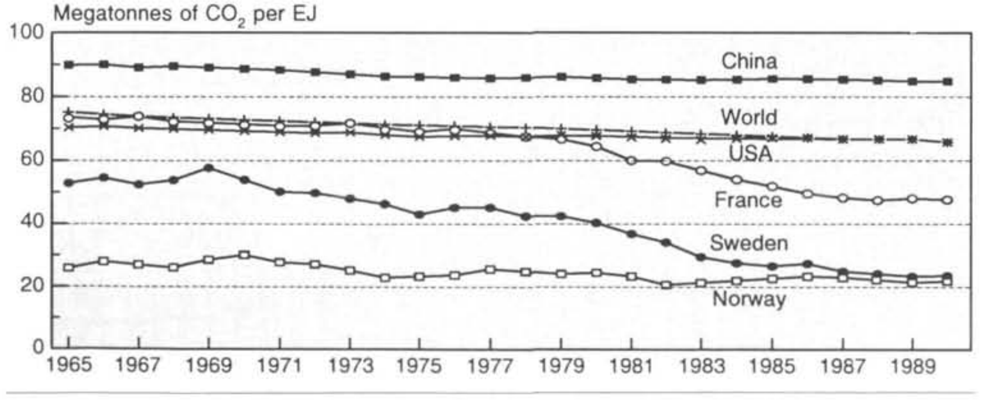


Percentage of CO_2 avoided by the use of nuclear energy and hydropower

Nuclear energy use and CO_2 emissions



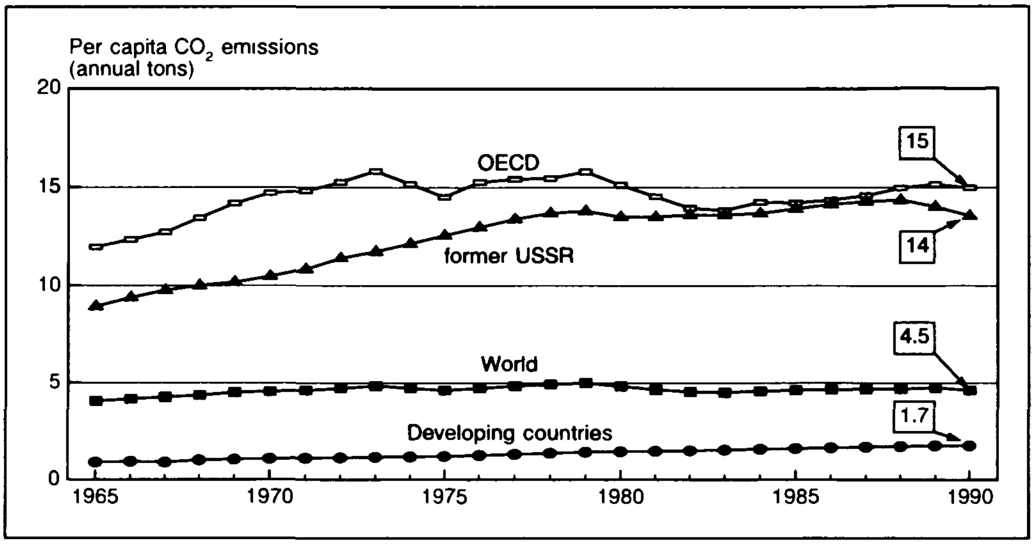
Countries: P = Portugal; D = Denmark; GR = Greece; IT = Italy; T = Turkey; NE = Netherlands; R = Romania; PO = Poland; AL = Albania; IR = Ireland; N = Norway; AU = Austria; GDR = former German Democratic Republic; Y = Yugoslavia; USSR = former Soviet Union; UK = United Kingdom; CSFR = former Czechoslovakia; H = Hungary; B = Bulgaria; FRG = former Federal Republic of Germany; S = Spain; BE = Belgium; F = Finland; SW= Switzerland; SE = Sweden; FR = France.



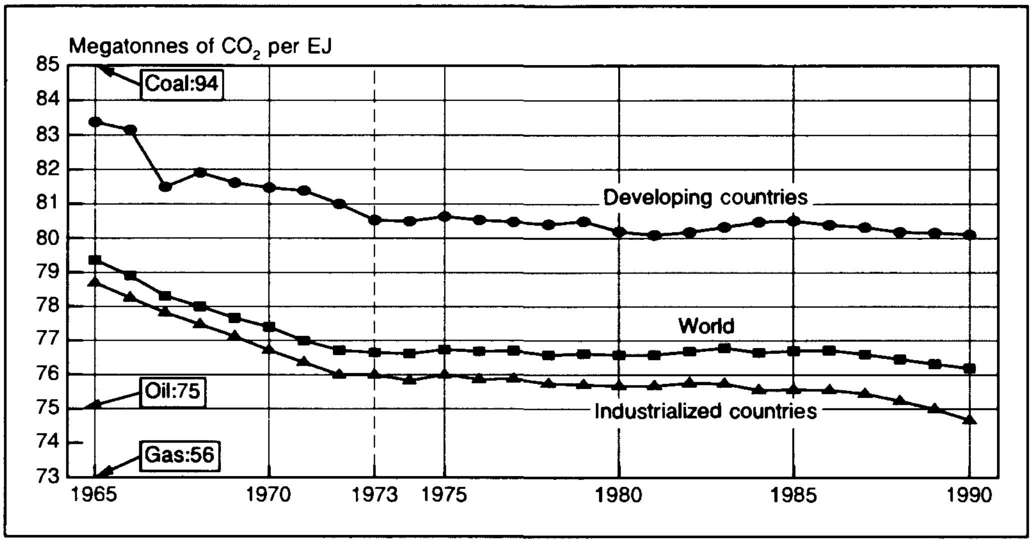
Shares of fossil fuels in energy consumption and selected national CO_2 emissions

	Fossil share (%)	Non-fossil share (%)		
		Nuclear	Hydro	Total
China	95	0	5	5
France	65	30	5	35
Norway	29	0	71	71
Sweden	34	31	35	66
United States	88	8	4	12
World	87	6	7	13

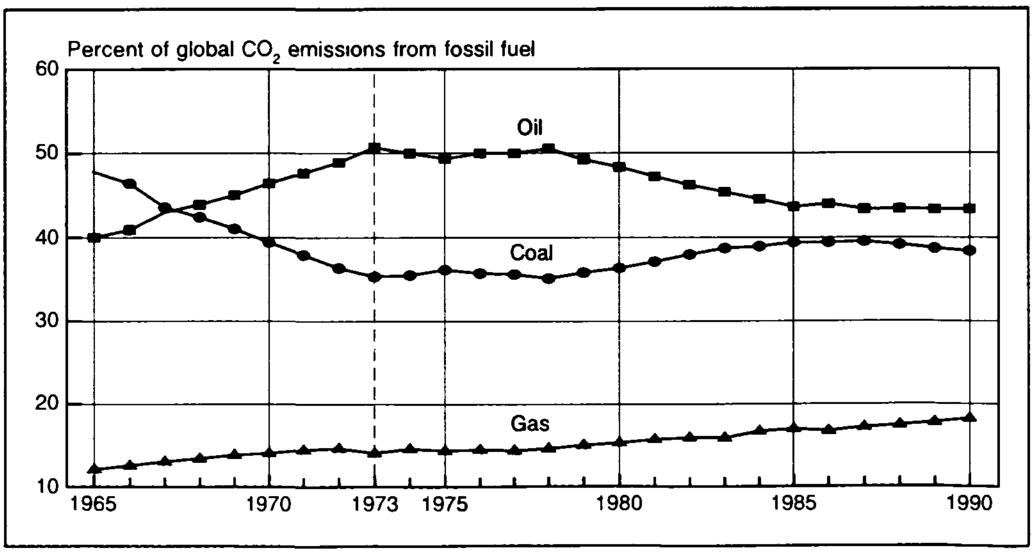
Per capita CO2 emissions by country groups



Trends in CO2 emissions, 1965-90



Percentage of CO2 emissions from the use of fossil fuels

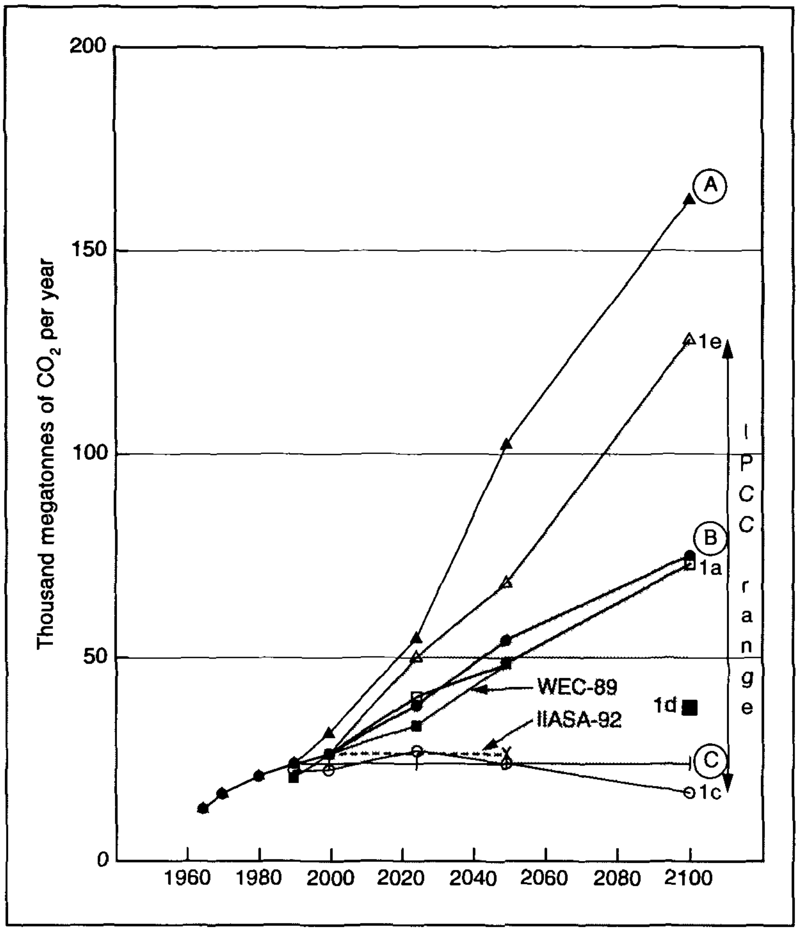


2020, assuming a rather low population growth of 1.4% per year to 2020. The WEC-89 reference case assumes a continuation of economic growth rates achieved in the second half of the 1980s and a faster reduction in energy intensity than historically recorded. Nuclear power would increase its share of primary energy supply worldwide by about 50% in the period 1990 to 2020. This stems from the WEC Commission's view that, with sustainability in mind, the nuclear option needs to be reevaluated, taking into account environmental issues and security of supply.

IIASA scenario. The IIASA-92 scenario, which assumes a large share of nuclear power in the energy supply, gives additional support to the view that non-CO_2 emitting technologies have to contribute substantially to energy supply in a greenhouse benign policy.

Other cases. Three other cases have been developed at the IAEA, based on views laid down in the Framework Convention on Climate Change. This Convention stresses worldwide equity of industrialized and developing countries as one of the basic concepts for sustainable development. This means that closing the socio-economic gap between rich and poor countries should be one of the pillars of a global climate policy. It also implies a future with regionally more balanced *per capita* energy consumption and CO_2 emissions. This likely is also a *conditio sine qua non* for full collaboration of developing countries in a global policy for sustainable environment. Nowadays, the average *per capita* energy consumption and the related *per capita* greenhouse gas emissions are one order of magnitude higher in industrialized than in developing countries. Therefore, the global demand for energy could become much larger in the next century for equity reasons and if, as expected, the world population grows to almost three times the present level.

The three cases analyze different ultimate equity levels, which are assumed to be reached in the course of the next century. This was done to illustrate the constraints for a sustainable global energy policy which aims at decreasing the lifestyle-determined economic gap between developing and developed countries. The cases further assume that worldwide equity of *per capita* CO_2 emissions is approached with a rate of 3% change per year in the ratio of *per capita* CO_2 emissions of industrialized to developing countries. The world population is assumed to reach 12 billion in 2075, which is in line with what the UN Population Fund considers likely. For the sake of transparency, it was assumed that there would be no shifts in fuel mixes and efficiency improvements.



Scenarios of energy-associated CO_2 emissions

Three cases were considered:

Case A. This case assumes that industrialized countries stabilize their *per capita* energy consumption and CO_2 emission at 1990 levels, and that developing countries make up their arrears in 50 years time. The result is not surprising, namely a huge global release to a level of 150 000 megatonnes of CO_2 per year — which is almost six times more than the present annual emission rate of 24 000 megatonnes.

Case B. This case assumes that in 2050 the global equity level of *per capita* energy consumption will be four times the present level in the developing countries and 2.5 times smaller than the present level in industrialized countries. This would imply the maximum feasible rate of investment in development. The resulting ultimate CO_2 emission rate of about 75 000 megatonnes of CO_2 per year is still very high, though in the range of the IPCC scenarios.

Case C. This is a normative case constrained by an assumed global rate of CO_2 emissions stabilized at the 1990 level. Equity is reached only at the end of the next century. This means, however, that not even the Toronto global goal (a 20% reduction from 1988 levels by the year 2005) is met. Nevertheless, this case is more or less identical with the IPCC scenario-1c, which assumes extensive nuclear development and is the lowest of all IPCC CO_2 emission scenarios. Implicit in this case is that the industrialized countries lower their CO_2 emissions by 70% and 80% in 2050 and 2100, respectively, in order to compensate for the increasing emissions from the developing countries. This would require a reduction target of about 100 million tonnes of CO_2 per year. The implied nuclear plant capacity expansion is clearly feasible, since it is comparable to the rate of plant installation that has already been achieved in the early 1980s.

Taken together, the three cases show that without strong measures the emission rates of greenhouse gases like CO_2 will increase to exceptionally high levels, mainly due to population growth and the equity-invoked lifestyle improvements in the developing countries. Furthermore, these cases imply that nuclear energy is required for achieving a worldwide strategy to abate climate change. This, in turn, would require more extensive involvement by developing countries in generating electricity using nuclear energy.

Reinforcing commitments

Energy scenarios assuming explicit contributions from nuclear power to energy supply clearly show that global emissions of CO_2 can be substantially reduced if nuclear energy can further penetrate the electricity market. A bundle of measures, including nuclear energy and energy efficiency improvements, is required in order to lower greenhouse gas emissions to a level at which no further anthropogenic perturbation of the greenhouse and associated climate change will take place. This implies a very large worldwide effort from both industrialized and developing countries, the latter needing substantial support in terms of funds, expertise and hardware, all aiming at lowering greenhouse gas emissions.

As a first step, however, all industrialized countries need to demonstrate that they take the greenhouse problem seriously by lowering their own, presently dominating, contributions to global emissions of greenhouse gases. In this context, countries inclined to phase-out nuclear energy will have to become convinced that such a move would make it difficult, if not impossible, to keep their commitments of at least stabilizing CO_2 emissions, much less reaching the Toronto global target. ❐

An important share of electricity in Chicago and other cities around the world is generated by nuclear energy. *(Credit: ENEL)*

Electricity production and waste management: Comparing the options

An IAEA survey compares cost estimates for managing wastes from the production of electricity using nuclear and fossil fuels

by V. Tsyplenkov

Many years have passed since the advent of nuclear power was hailed as providing "electricity too cheap to meter". Nevertheless the main motivation for nuclear power development programmes is to provide an affordable and secure source of electricity both for the short and long term. The cost at which electricity can be provided is therefore a highly important issue, as is the choice of the method for calculating this cost. For many years, the relative costs of different methods of electricity generation have been estimated and compared by a wide range of organizations, including the IAEA, in order to develop a proper perspective.

Since the initial development of nuclear fission reactors, radioactive waste management has often been seen as one of the major problems of nuclear power. Concerns have extended to the costs involved, in particular the cost associated with the disposal of high-level waste or unprocessed spent fuel. This cost has been widely used, not always objectively, by opponents of nuclear power in their arguments. More recently, environmentalist organizations have started to realize that all forms of energy production generate waste and have environmental effects which may be unacceptable, if not adequately controlled. The escalation over the last few years of topics, such as the "greenhouse effect" and "acid rain", into major political issues, has led to more detailed consideration of the waste management aspects from burning fossil fuels. These have hitherto been very loosely regulated, particularly in some parts of the world. We are now at a stage where the management of wastes from nuclear power remains very highly regulated and where the regulations for the control of wastes from fossil fuel power stations are being significantly tightened. Since it is almost certain that a substantial proportion of electricity will continue to be generated from both these sources, it is an opportune time to review the waste management practices and their costs.

This article is based on a survey carried out by the IAEA of existing waste management cost estimates. A number of cost studies have recently been completed for different stages of waste management. It was considered useful to collect the results of these studies and to compare them objectively with the waste management costs of electricity production from other energy sources. The comparison can then be used to provide a correct perspective of the economic and environmental aspects of the different means of production of electricity.

The comparison is made for the costs of managing waste generated in the production of electricity from representative nuclear and fossil fuel cases. The associated costs from the third major source of electricity, hydropower, are obviously small and thus not considered here. Both fossil and nuclear fuels can be exploited in a number of different types of plants. Since it would be impractical to consider all possible variants, representative plants having a capacity of 1000 megawatts-electric (MWe) were selected for the assessment, each operating at a capacity factor of 70% for 30 years.

Nuclear and fossil fuel cycles

Fossil fuel cycle. Coal is the leading fossil fuel used for electricity generation in the industrialized world, although the share of gas is increasing rapidly. In some countries, oil is also an important fuel for electricity production, but many try to avoid its use because of possible rapid changes in the price of oil. From the standpoint of waste arisings, oil is somewhere between coal and gas. Because of this, coal and

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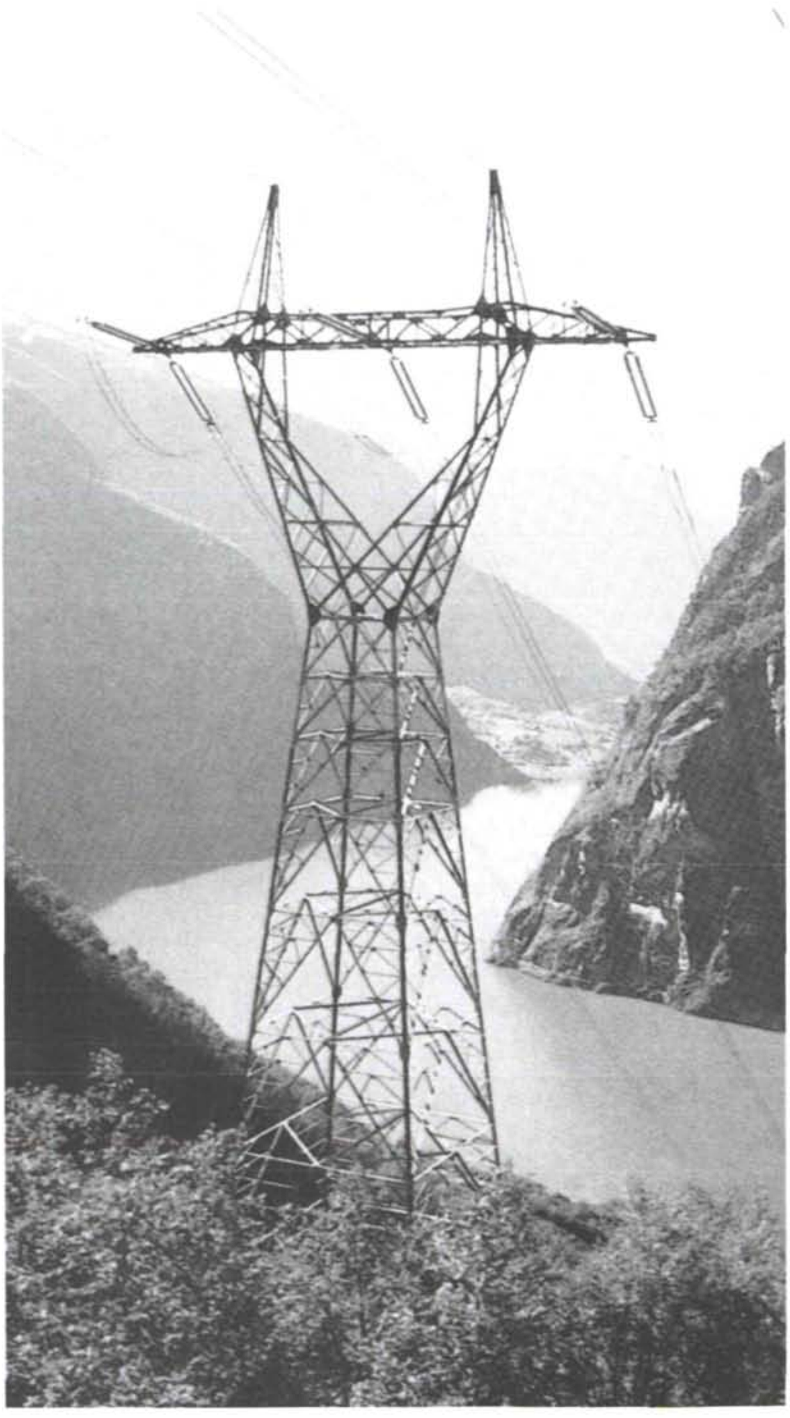
gas have been chosen as the representative fossil cases for the comparison.

Modern coal plants are fired by pulverized coal. Upon cumbustion, the coal reacts with oxygen to form carbon dioxide (CO_2). The combustion process is accompanied by the production of oxides of nitrogen (NO_x), sulphur dioxide (SO_2), fly ash, and a number of other polluting by-products including radionuclides contained in coal.



Electrical lines in Norway. *(Credit: NorEnergi.)*

For baseload electricity production, two types of gas-fired plants are available. The first is a conventional steam cycle (CSC) plant. More recent units, however, use gas turbines in front of the steam cycle to improve the efficiency of the unit: this combination is called a combined cycle (CC) plant. The combustion process of natural gas is much cleaner than coal. The main combustion products are CO_2, water, and NO_x.

A conventional coal plant and a gas-fuelled combined cycle plant are likely to be the major sources of new fossil-fuelled electricity generation. They represent both ends of the spectrum of challenges associated with waste management from fossil fuels. *(See diagram, page 30.)*

Nuclear fuel cycles. Nuclear power plants generate electricity from the heat produced when the nuclei of the atoms of heavy elements are split. The heat is used to produce steam to drive turbines which generate electricity.

Uranium is currently the principal nuclear fuel. It occurs in nature and is mined by conventional mining techniques. It is then processed into a form suitable for use as fuel in a nuclear reactor. Natural uranium contains two main isotopes, uranium-238 and uranium-235. Only the nuclei of the uranium-235 atoms are readily fissile, but uranium-235 accounts for only 0.7% of natural uranium. Some reactors use natural uranium for fuel, but most reactors now use slightly enriched uranium, in which the proportion of uranium-235 atoms has been increased (or enriched) to a few percent. Consequently, most uranium is enriched before it is fabricated into fuel elements for loading into a reactor.

When the spent fuel is removed from the reactor, typically annually, it contains unconsumed uranium, fission products, plutonium, and other heavy elements. It is possible to dissolve the spent fuel and chemically process (reprocess) it in order to extract the unused uranium and plutonium for fuel fabrication and recycling. Alternatively the spent fuel elements can be disposed of directly as waste, without reprocessing.

The two main types of fuel cycle are the once-through thermal neutron reactor cycle and the thermal neutron reactor cycle with reprocessing. *(See diagram.)* In the "once-through" thermal reactor cycle the spent fuel is not reprocessed but kept in storage until it is eventually disposed of as waste. In the thermal reactor cycle with reprocessing, the spent fuel is reprocessed and uranium and plutonium are separated from the fission products. Either the uranium, the plutonium, or both can be recycled in new fuel elements.

There are a number of thermal reactor types currently in use for electricity generation. The dominant one worldwide is the pressurized water reactor (PWR). It has therefore been selected, both with and without reprocessing, as the nuclear reference case for this comparison. Although the other types of reactors produce wastes which are different in some details to those from a PWR, it is considered that the PWR is sufficiently representative to be the reference case.

Waste arisings

Waste arises at each step of the fuel cycles: mining, fuel fabrication or preparation, power production, and decommissioning.

Electricity generation from nuclear fuel produces substantially different wastes both in quantity and type to those which arise from electricity generation using fossil fuel. The waste arisings from the operation of nuclear power plants are in the form of relatively small volumes of radioactive material. In contrast, fossil-fuelled plants burn large quantities of fuel and the operational waste arisings include large amounts of combustion products. Both types of power plants produce wastes in gaseous, liquid, and solid forms.

It is not widely appreciated that the combustion of coal releases quantities of radiation to the environment that are similar (in terms of its potential biological consequences) in magnitude to the routine releases from the nuclear industry for comparable electrical output. Natural gas production and usage also release radioactive radon to the atmosphere.

Fossil fuel wastes. Most of the wastes from fossil fuel cycles arise during power production, although for coal substantial amounts of solid wastes are also produced during mining and fuel preparation.

Combustion of fossil fuels produces carbon dioxide. Compared with coal, burning natural gas produces somewhat more than half the CO_2 on a per unit energy content basis. Coal combustion also produces oxides of sulphur (SO_2 and SO_3) while gas combustion products have almost no sulphur compounds. The combustion of coal and gas also produces oxides of nitrogen (NO_x).

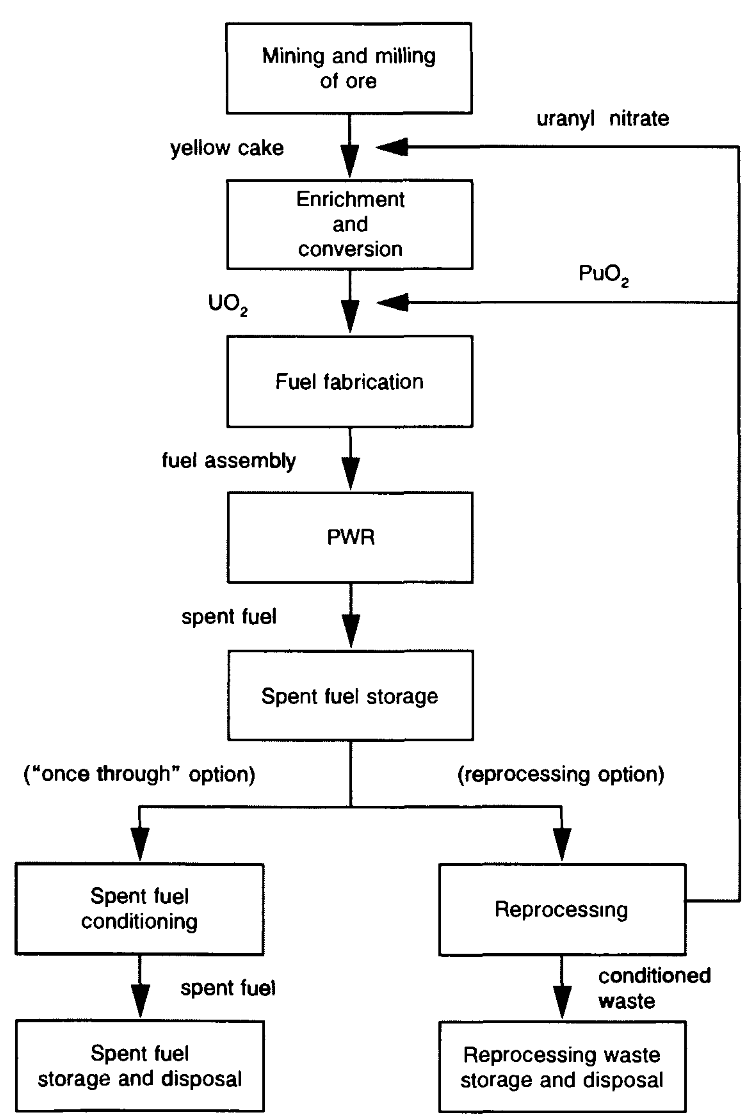
Particulate emissions (ash) also occur with the combustion of coal. Part of the ash, about 10%, remains in the boiler and is removed; this is called bottom ash. Most of the ash, however, appears as a very fine particulate material in the flue gas; this is known as fly ash.

For fossil facilities, decommissioning will likely occur soon after the end of a plant's operating life. Decommissioning wastes will generally be those associated with demolition, and would not pose special residual hazards.

Arisings of conditioned radioactive wastes

Step	Waste category	Unit	Range low	Range reference	Range high
Mining and milling	LLW	m^3/a	20 000	40 000	60 000
Conversion and enrichment	LLW	m^3/a	20	20	20
Fabrication	LLW	m^3/a	20	30	30
Power plant operation	LLW	m^3/a	100	130	200
	ILW	m^3/a	50	80	100
Reprocessing	C1	m^3/a	3.5	4	4
	C2	m^3/a	20	22	25
	ILW	m^3/a	50	75	100
	LLW	m^3/a	470	580	690
Spent fuel (unconditioned and once-through)		t/a	25	30	35

Nuclear fuel cycle considered for assessment



Coal waste streams after waste treatment

	Waste streams (g/kWh)
NO_x	0.25
SO_2	0.32
Fly ash to air	0.07
Fly ash collected	3.02
Gypsum	2.10

Nuclear wastes. As in fossil fuel cycles, wastes occur at each stage of the nuclear fuel cycle.

Mining wastes consist mainly of mine waters and waste rock piles. While uranium mill tailings are generally similar to mining wastes, they contain nearly all of the naturally occurring radioactive daughters from the decay of uranium.

The conversion and enrichment processes produce solid and gaseous wastes which contain some airborne uranium. In addition, enrichment plants produce large volumes of depleted uranium which is considered as a waste for purposes of this assessment.

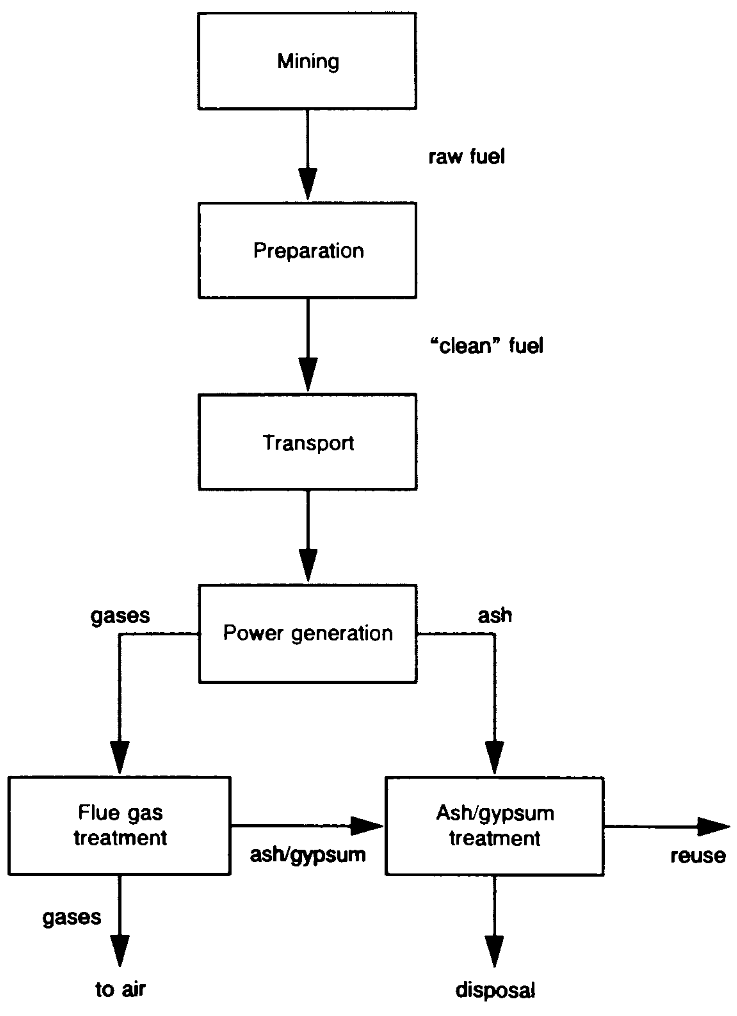
Depending on whether reprocessing is employed, fuel fabrication wastes are in the form of various solid and liquid streams contaminated with uranium and/or plutonium.

Radioactivity occurs in various liquid waste streams of the power plant. In addition, small quantities of gaseous waste are generated during reactor operation. Reactor operations also give rise to a range of solid wastes in the form of contaminated or activated components.

The radioactive content of reprocessing wastes consists largely of the fission and activation products and minor actinides that are fed into the reprocessing plant as part of the spent fuel. They occur as a variety of solid and liquid waste streams.

The radioactive nature of some of the components of nuclear fuel cycle facilities requires expensive remote handling techniques to be employed during decommissioning. The cost and need for such an approach can be reduced by delaying the work and allowing decay of radioactivity. For nuclear power plants, deferred decommissioning is a strategy commonly employed throughout the world and has been selected as the reference for the purpose of this assessment. Most of the radioactive waste from decommissioning nuclear fuel cycle facilities is low-level (LLW) solid waste. Small components of intermediate level (ILW) and high-level (HLW) or transuranic waste are associated with reprocessing of spent fuel and the fabrication of mixed-oxide fuel.

Fossil fuel cycle considered for assessment



Waste management

Fossil wastes. The largest solid waste management problem faced by the coal cycle is that related to mine spoils. These pose a significant disposal problem. One possible option includes backfilling in the mines from which they came.

The flue gas treatment in a coal plant consists of three steps: NO_x removal, SO_2 reduction, and particulate reduction. For natural gas, the only significant flue gas waste management problem currently capable of resolution is that associated with nitrogen oxides.

Modest NO_x reduction is achieved by modification of the combustion process. However the most effective process for NO_x removal is selective catalytic reduction (SCR) which uses ammonia and a catalyst to reduce the NO_x to nitrogen and water. Typical SCR reduction rates are around 80%. Used catalytic material is the only waste that requires disposal as a result of this process. However, the main component can be returned to the supplier for reuse.

Flue gas desulphurization (FGD) processes use alkaline materials to absorb and remove the sulphur dioxide from the flue gas. FGD processes tend to be large and expensive since very large volumes of flue gas containing very low concentrations of SO_2 must be treated. Large quantities of product (gypsum) result from the reaction of the sulphur dioxide and the reagent. Some of this can be treated to produce a wallboard quality gypsum and the rest is disposed of as landfill. Typical FGD removal efficiencies are 95%.

The reduction of particulate in the flue gas is usually achieved using electrostatic precipitators (ESP) which typically have a removal efficiency of about 95%. Some of the removed fly and bottom ash can be utilized in the cement and road building industries, the remainder requires disposal as landfill.

At present, there is no cost effective technology which will reduce CO_2 emissions and no attempts have been made on removal of radionuclides from gas effluents. Various waste streams are discharged into the environment after waste treatment. *(See table.)*

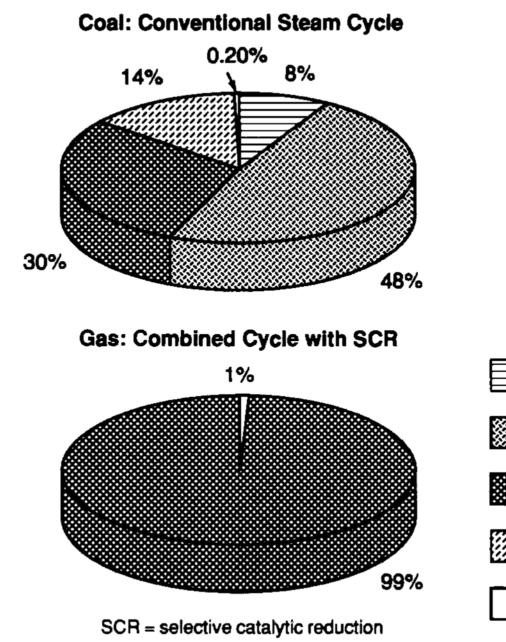
Nuclear wastes. A number of techniques are currently used in the management of radioactive wastes. These range from direct discharge to the environment (dispersal) to sophisticated techniques for immobilization of the radionuclides and their disposal in carefully designed and constructed disposal facilities.

Mining and milling waste. All wastes arising from the milling of uranium ores are treated before any release takes place. The disposal of mill tailings is usually done on-site, often by covering the tailings to reduce radioactive dispersion.

Liquid wastes. Liquid waste treatment forms a significant part of the waste management scheme at most nuclear facilities. The waste management option depends on the characteristics of the waste and the quantity being produced. Small quantities of aqueous wastes containing short-lived radionuclides may be discharged into the environment. Liquid wastes containing large salt concentrations can be evaporated with the radioactive material being retained in the concentrate or being chemically precipitated to produce a sludge with suitable properties for further treatment. Some liquid wastes can be absorbed on solid matrices, again as a precursor to further treatment of the solid. Incineration is also sometimes used for volume reduction of active oils and combustible solvents. LLW and ILW concentrates are encapsulated in cement or bitumen matrices, and then packaged in suitable containers.

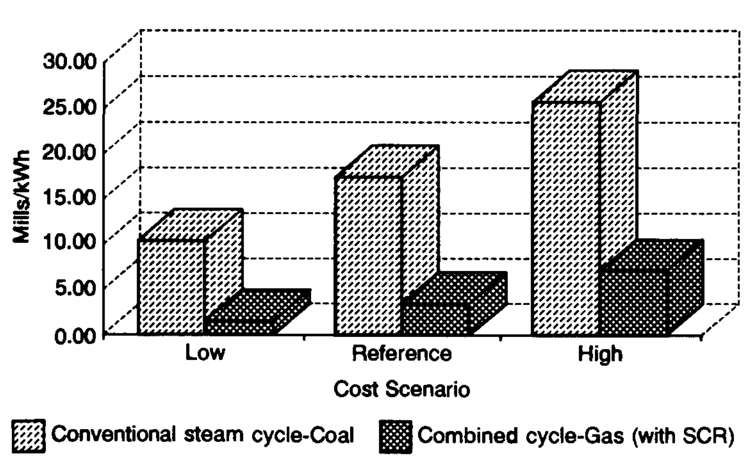
Liquid HLW from a reprocessing facility contains almost all of the fission products produced in the fuel. Currently such HLW is converted into glass using a vitrification process and the molten glass is cast into stainless steel containers prior to disposal in a suitable deep repository. (These high-level heat emitting wastes are classified as C1 in this assessment.)

Gaseous wastes. Radioactive gaseous wastes are usually discharged in the atmosphere in accordance with the appropriate regulatory requirement. Before discharge, the gaseous wastes are treated, if necessary, to ensure that the



Fossil fuel waste management cost estimates

Comparison of levelized costs: Fossil fuel waste management

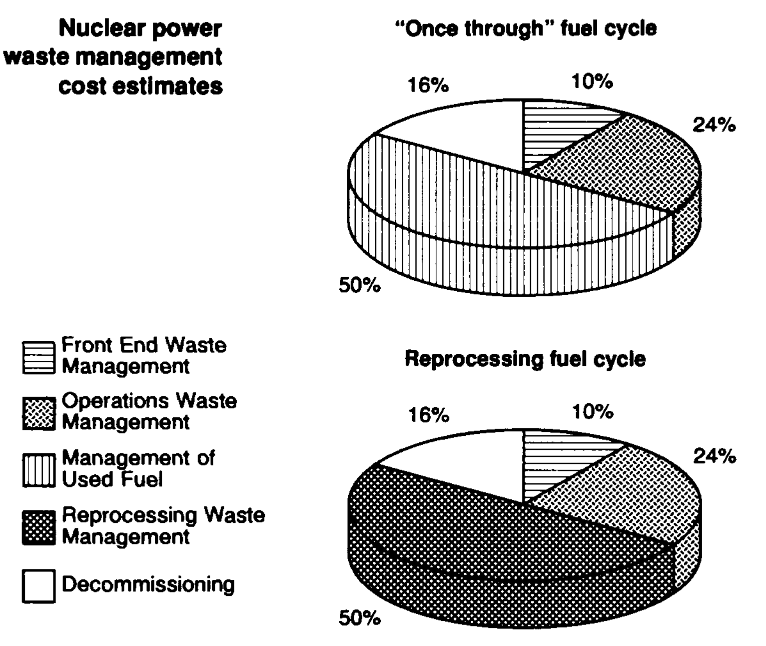


regulatory limits on the discharges are not exceeded.

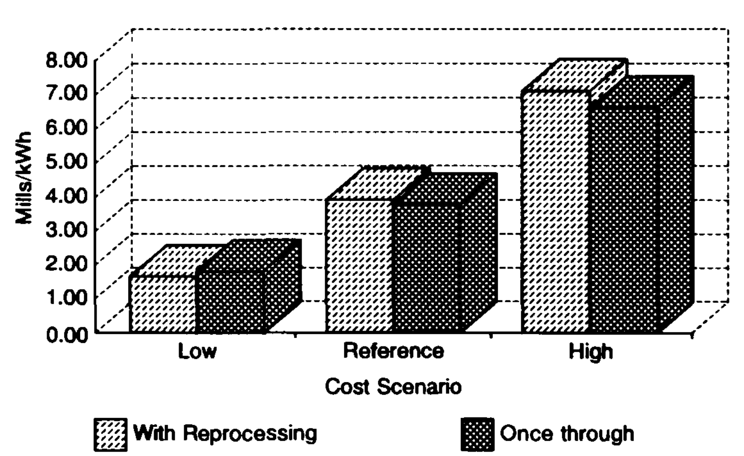
Solid wastes. Apart from already mentioned vitrified reprocessing wastes, solid wastes also include cladding hulls and fuel assembly hardware (classified as C2), filters, used equipment, resins and sludges, scrubber solids, and general trash. All of the waste, except that with very low activity levels, will need some treatment and conditioning.

Treatment and conditioning operations include volume reduction, conversion of the waste to more stable forms, and packaging. The various stages of waste management for the PWR cycle considered here produce different volumes of conditioned solid wastes. *(See table, page 29.)*

Nuclear power waste management cost estimates



Comparison of levelized costs: Nuclear waste management



Disposal in a suitable facility, which may be deep geologic or near surface, contributes to limiting any transport of radionuclides into the environment to acceptable levels. For the once-through cycle, spent fuel is stored for a period of years, probably several decades to allow the radioactivity and associated heat load to decay before disposal.

Methodology for cost assessment

The data for each of the cost components of waste management have been obtained from a survey of existing estimates. In order to provide a basis for a meaningful comparison of costs, the raw data have been adjusted where necessary and applied to the reference cases. Finally, all cost estimates have been converted to a common basis of levelized unit energy (LUC) costs expressed in US dollars as of 1 July 1991, per kWh. The LUC is defined such that the present value of the cost stream equals the present value of the single value levelized cost times the number of units (kWh) in each timeframe. In order to put waste management costs on a common basis for comparison purposes, it is necessary to convert all cost flows to a common value by the procedure of discounting. This is widely accepted in economic assessments as a procedure which facilitates the comparison of investment options having distinct cash flows spread out in time.

The major criticism of applying the discounting technique to the assessment of the cost of nuclear power is its application to significant cost streams long after the production of electricity from the nuclear generating station ceases. This criticism relates to intergenerational equity — that is, the extent to which electricity customers pay the full costs of serving them and the extent to which future generations bear costs from which they receive no benefit.

In order to recognize this concern, the reference cases are based on a 5% real discount rate to the end of power plant life followed by a zero discount rate thereafter. A 5% real discount rate is favoured by many countries of the Organization for Economic Co-operation and Development (OECD). In addition, the results have been tested for sensitivity to different factors: the discount rate, the capacity factor, and the service life of the power plant.

Cost data

Fossil fuel cycle. For both fuel cycles the levelized waste management costs cover a range of about 0.5 to 2.0 times the reference cases. *(See graphs.)*

When looking at the relative proportions of these costs, the control of SO_2 alone contributes about 48% of the costs in the conventional steam cycle coal plant. For the combined cycle, 99% of the waste management costs are comprised of the decommissioning cost.

Fossil fuel waste management costs are in the range of close to zero to about 25 mills per kWh (a mill is one-thousandth of a US dollar). The costs are expected to remain in this range with typical variations in capacity factor discount rate or service life. The low end of the range corresponds to gas-fired generation and the high end to coal-fired generation. At these levels, waste management costs represent a low to moderate fraction of the overall cost of baseload electricity generation from fossil fuels. Total levelized costs of fossil-based electricity generally fall in the range of 40-60 mills per kWh.

Nuclear fuel cycle. The levelized cost of waste management for the two nuclear fuel cycles assessed are similar. *(See graphs.)*

For both cycles, waste management at the front end of the cycle leads to about 10% of the total waste management cost. Of this, about one-third is due to the management of depleted uranium as a waste. The management of wastes from power plant operation accounts for about 24% of the costs and 15% is due to power plant decommissioning. The remaining 50% of costs is associated with the back end of the fuel cycle.

Nuclear waste management costs are in the range of 1.6 mills/kWh to 7.1 mill/kWh. As in the case of fossil waste management, such costs represent a low to moderate fraction of the cost of electricity generated. The waste management costs may be compared to the cost of nuclear powered electricity, which is 30 to 50 mills/kWh.

Comparison. The waste management costs for the nuclear cases lie between those of the two fossil cases. They are closest to the costs for gas-fuelled combined cycle, which represents the lower end of the fossil range. The coal-fuelled option, representing the top end of the fossil range, has waste management costs which are about a factor of four above those of the nuclear cases.

While both the nuclear cases show a range between the high and low values covering a factor of four, the variability in fossil cost estimates only cover a factor of two or less. This difference in variability can in part be attributed to the fact that the fossil costs are based on established technology, while the nuclear costs include a substantial contribution from waste management activities which have yet to be firmly established. Even though flue gas treatment is a relatively new field, several plants are in operation and the cost estimates are firmer than those for some nuclear waste management techniques, such as decommissioning and deep repositories. In light of this, there is greater uncertainty associated with nuclear waste management costs than with those fossil waste management activities considered in this assessment. Some of the difference in variability between fossil and nuclear waste management cost estimates is also due to the effect of differences between local conditions, including regulatory requirements.

Possible future changes

For nuclear generation a major shift in waste management practices or expectations is not foreseen. Nonetheless the future holds some possibilities that could influence waste management costs. These include attempts to increase fuel burn-up, better housekeeping, and more effective and advanced waste treatment techniques, such as supercompaction, biodegradation, incineration, and plasma torch burning. All of these developments hold the promise of reducing nuclear waste management costs. The future will also bring the development of deep repositories and much greater experience with decommissioning. While these bring with them the risk that costs might turn out to be higher than expected, they will also significantly reduce the uncertainty with respect to nuclear waste management costs.

In the case of fossil waste management costs, one of the major developments is expected to be the more widespread use of clean coal technologies. This will result in reduced environmental impacts and waste management costs through a technology that better integrates emission control within the power generation process itself. A further possible development related to fossil-fuelled generation is regulation with respect to CO_2. This could involve the development of technological solutions such as the disposal of CO_2 in empty gas fields at the bottom of the ocean, or the introduction of carbon taxes — both of which could significantly increase fossil waste management costs.

For both nuclear and fossil cases, there is also the possibility that existing waste management regulations will be further tightened. This would include the possibility that residual environmental costs would have to be internalized by electric utilities. Such changes would bring with them increased costs. ❐

Strengthening nuclear and radiation safety in countries of the former USSR

The UNDP and IAEA join forces with newly independent States to build adequate national infrastructures for nuclear safety

by Morris Rosen

Early in 1994, a multimillion dollar international programme will be fully under way for providing practical assistance to successor States of the former Soviet Union in areas of nuclear and radiation safety.

The initiative was launched at a ministerial level *Forum for Information Exchange* at IAEA headquarters from 4-7 May 1993. Senior governmental officials of these countries outlined their existing programmes, problems, needs, and priorities as part of efforts to determine how assistance under the international programme can best be directed. The programme is a joint initiative of the IAEA and the United Nations Development Programme (UNDP). Funding and other support for assistance services is being sought from governments, international funding agencies, and private industry.

The joint programme is designed to include areas not covered by international efforts already in place for assisting countries in Central and Eastern Europe in the nuclear power sphere. These include bilateral and multilateral assistance programmes to improve the safety of nuclear power plants, including a co-ordination structure set up by the Group of 24 countries of the Organization for Economic Co-operation and Development (OECD) through the Commission of the European Communities (CEC) in Brussels. The IAEA itself is carrying out comprehensive programmes for each of the various generations of pressurized light-water reactors, known as WWERs, and the graphite moderated RBMK reactors. These reactors are located in Lithuania, Russia, and the Ukraine, all countries emerging from the former USSR, and also in Bulgaria, the Czech Republic, Hungary and the Slovak Republic.

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There have been no collective initiatives to deal with the more widespread problem of the safety of facilities such as research reactors, uranium mining and milling facilities, and installations containing radiation sources used in medicine, agriculture, and industry. The new joint programme takes advantage of the IAEA's extensive experience in building safety infrastructures, including legal and regulatory frameworks, and the UNDP's ability to obtain funding and to build national capabilities for management of assistance. The UN system provides impartiality and universality which may offer governments and donor organizations an appropriate mechanism for furnishing assistance. United Nations Integrated Offices have been opened in most of the newly independent republics to allow for a more consolidated and collaborative approach to assistance efforts of organizations within the United Nations system.

The first steps

The joint programme was planned as a three-step operation beginning with the Vienna forum which had representation from Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrghyzstan, Latvia, Lithuania, Moldova, Russia, Ukraine, and Uzbekistan. *(See maps.)* Two of the newly independent republics, Tajikistan and Turkmenistan, did not attend. Here, sufficient details were obtained to outline an action plan. It was recognized that country-specific assistance programmes would need to provide up-to-date equipment along with specialized expert and advisory services. Information exchange and training activities to include workshops and scientific visits equally would play an important role in bringing about the needed exposure to the international scientific community and to international practices.

Financing could be the limiting factor in providing assistance, and observers from potential donor countries and financial organizations were also invited to the Vienna forum. Among these were the CEC, the Group of 24, the European Bank for Reconstruction and Development, and the World Bank.

Some main problems

IAEA consultants followed the deliberations at the forum and held extensive discussions with participants in special working groups. There was one clear finding. An acute need exists to develop independent national approaches to replace the void produced by the breakup of the former Soviet Union.

All countries had provisions for radiological protection but were dependent for direction and advice on All Union organizations in the former USSR. The breakup of the Soviet Union removed these arrangements as well as the central authority based in Moscow. The creation of new self-reliant national authorities and institutions as well as legislation and standards has became a priority concern. While national approaches are being established, there is duplication of responsibility in some areas and a lack of adequate responsibility in others. Ministries dealing with health and others concerned with the environment or industry along with State committees and institutes can all be involved.

Authorities and institutions will need to develop their own expertise in the policy as well as in the technical sphere. Training courses to demonstrate international practices were called for by most delegations. An awareness of the standards of protection that are accepted worldwide, such as the Agency's *Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources*, will be an essential step in building the new safety infrastructures.

There are common problems. All countries have radiation sources for use in medical therapy and industrial radiography while some also employ them for product sterilization purposes. There are sources of unknown composition and quantity which have been abandoned and their whereabouts are not known. The safety of shallow land burial waste disposal facilities which have existed in most countries since the early 1950s is in several cases largely unknown or unsatisfactory. Where uranium has been mined and processed there are problems with the stabilization of spoils and tailings. Decommissioning of research reactors and fuel cycle facilities will eventually require attention.

There is a general lack of emergency response capabilities, particularly in the communication area and in the ability to carry out radiological analyses. A number of countries were also concerned about the adequacy of nuclear safety in neighbouring republics.

The initial fact-finding missions

The programme's second phase is now under way through fact-finding missions of specialists which will be carried out in each country and completed by early 1994. They will lead to detailed country-specific assistance packages as well as efforts directed at groups of former Soviet republics with similar needs.

The first missions were undertaken in July 1993 to Kazakhstan, Uzbekistan and Kyrghyzstan. *(See accompanying box and maps.)* They were carried out by Agency staff and one consultant who had also participated in the Vienna forum. Nuclear power and research reactors, uranium mining and milling facilities, and the principal installations using radiation sources in medicine and research were seen. Discussions centred on legal frameworks for the use of nuclear energy; regulatory oversight including licensing and control of radiation sources and the safety of radiation workers; environmental protection and monitoring; waste handling; and emergency preparedness.

In all three countries, senior officials who had participated in the Vienna forum were active in making arrangements and in the discussions. Some principal observations from the fact-finding missions follow.

Legal and regulatory situation. While new national organizational arrangements are being established to oversee safety activities, many existing requirements and safety standards remain in force. There is a general recognition that rapid progress is desirable, but the time period will depend on overall priorities for governmental reorganization. Until completed, provisional bodies and regulations will probably continue to be used. Although safety documents of the former USSR are available, it appears that little other national or international material is accessible. Constructive co-operation with Russia will be essential as much relevant data and design information for the various nuclear installations remain there.

Personnel. Skilled administrative and technical staff are available; however, their experience is limited to operating within the former USSR system. Licensing and inspection staff seem to have good academic backgrounds but insufficient practical experience. There are

Selected characteristics of countries visited

Under the joint UNDP-IAEA international project, specialists have visited a number of countries to lay the basis for future assistance. The countries visited in July 1993 were:

Kazakhstan. The country has a population of 16.7 million and an area of 2.7 million square kilometers. The capital is Alma Ata. Kazakhstan declared its independence in December 1991. The country is rich in mineral resources. Coal mining, oil and chemical production, non-ferrous metallurgy, and heavy engineering are important industries. Kazakhstan's agriculture has changed from primarily nomadic cattle breeding to the production of grain, cotton, and other crops.

In the nuclear field, facilities include three research reactors at Semipalatinsk, which was the test site for Soviet nuclear weapons from 1949-89; one research reactor in Alma Ata; one breeder reactor outside Aktau; various uranium mining and processing sites; the Institute of Nuclear Physics near Alma Ata; and disposal sites for nuclear waste near Alma Ata and Aktau.

Kyrghyzstan. The country has a population of 4.4 million and an area of 0.2 million square kilometers. Its capital is Bishkek. Kyrghyzstan declared its independence in September 1991. It has over 500 large industrial enterprises, including sugar refineries, tanneries, cotton and wool cleansing works, flour mills, a tobacco factory, food processing plants, and timber, textile, engineering, metallurgical, oil and mining works. The country is known for its livestock breeding.

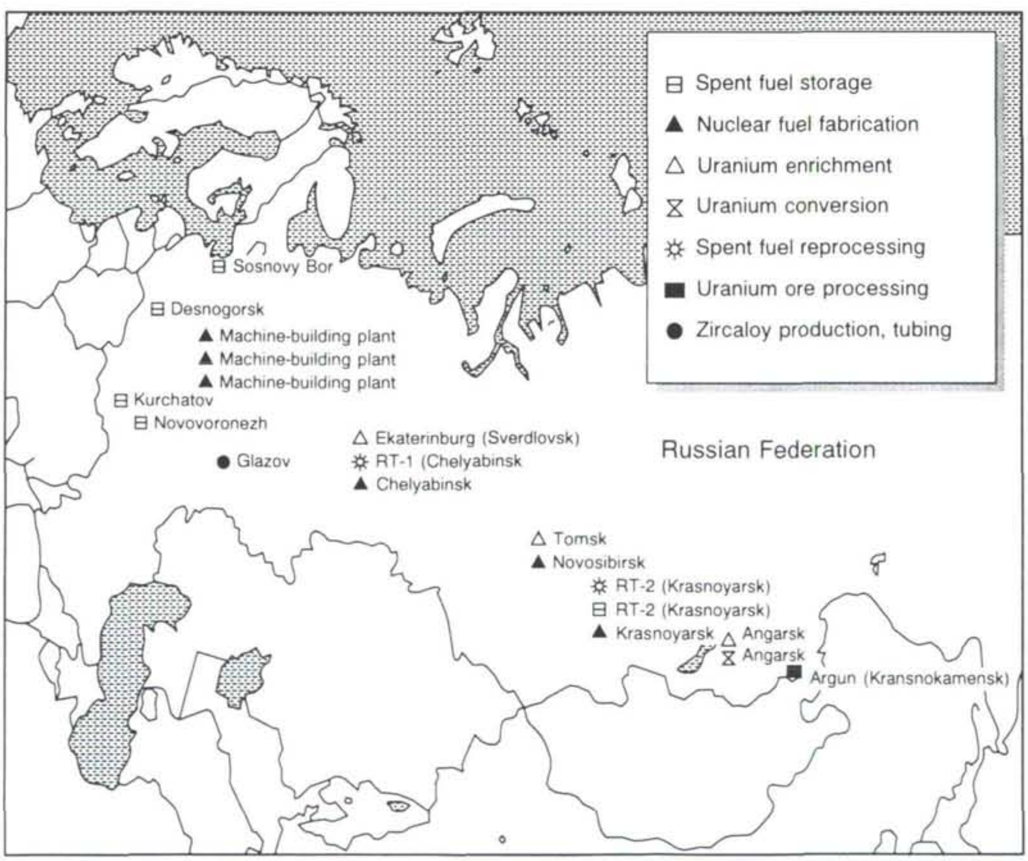
In the nuclear area, the main activities relate to uranium mining operations.

Uzbekistan. The country has a population of 20.3 million and an area of 0.45 million square kilometers. The capital is Tashkent. The country declared its independence in August 1991. It has approximately 1600 factories and mills with oil, coal, copper and building materials being the main exports. Uzbekistan is a land of intense farming based on irrigation, with cotton, rice and fruit being cultivated.

Nuclear facilities include a research reactor near Tashkent; a 15-kW pulsed neutron source at the Institute of Nuclear Physics; a uranium mining and milling site; and a central nuclear waste disposal facility.

Uranium open pit mining in Uchkouduk, Uzbekistan. *(Credit: C. Bergman, IAEA)*


Uranium processing
Uranium recovery from phosphoric acid
Nuclear fuel fabrication
Russian Federation
Tselinny
Semipalatinsk
Ust-Kamenogorsk
Kazakhstan
Aral Sea
Aktau
Prikaspiy Complex
Stepnoye
Alma Ata
Bishkek
Kyrgiz
Kyrghyzstan
Caspian Sea
Georgia
Azerbaijan
Armenia
Uzbekistan
Tashkent
Navoi
Chkalovsk
China
Turkmenistan
Tajikistan
Iran


Spent fuel storage
Nuclear fuel fabrication
Uranium enrichment
Uranium conversion
Spent fuel reprocessing
Uranium ore processing
Zircaloy production, tubing
Sosnovy Bor
Desnogorsk
Machine-building plant
Machine-building plant
Machine-building plant
Kurchatov
Novovoronezh
Glazov
Ekaterinburg (Sverdlovsk)
RT-1 (Chelyabinsk
Chelyabinsk
Russian Federation
Tomsk
Novosibirsk
RT-2 (Krasnoyarsk)
RT-2 (Krasnoyarsk)
Krasnoyarsk
Angarsk
Angarsk
Argun (Kransnokamensk)

many bilateral arrangements with Russia which include co-operative arrangements with various institutions. These will be maintained and provide some opportunity for personnel training. Senior level staff are being given opportunities for contact with the international scientific community and this should be extended to the more junior levels.

There has been a significant "brain drain" of Russian-born staff as a result of impending decisions on nationality and on language requirements. In Kazakhstan, the Kazakh and Russian populations are almost equal at about 40% of the total. The Russian component in Kyrghyzstan is 21% while in Uzbekistan it is only 8%. Russian scientists played an important role in many industrial and scientific bodies. In particular, operation of the BN-350 breeder reactor in Kazakhstan could be severely affected if it were to lose highly experienced technical and management staff.

The creation of the many new governmental bodies has also resulted in talented individuals being reassigned. The need to establish diplomatic missions worldwide has required not only political scientists, but also technical experts. The IAEA mission was the first official visitor to the new Foreign Minister of Uzbekistan who had just taken office; the previous two Ministers had been reassigned to embassies.

Facilities and equipment. Many facilities and much of the scientific equipment are old and outdated. The mission was continuously informed of a general shortage and deficient state of equipment, particularly of some common measurement devices. There is a lack of computers and software for modern information storage techniques and a general need for direct and rapid communication systems, not only for international but also for domestic use.

Facilities will need to be modernized with up-to-date equipment to bring operations up to international levels. However, in the short term it will be difficult to respond to the numerous requests for equipment without a better knowledge of priority work programmes and of the availability of sufficient staff. Requests for equipment will need co-ordination nationally.

A positive sign was the dedication of management and technical staff at the many industrial, research, and medical facilities visited. It was evidenced not only through their technical knowledge, but also the relatively good level of cleanliness and order at the installations. This was particularly obvious at the BN-350 nuclear power reactor in Kazakhstan. The plant has an excellent operating history and the areas visited were in an excellent state of housekeeping.

Public concern. In all three countries, there was concern about radioactive tailings from ongoing or discontinued uranium mining. However, it seems not to be an unduly serious problem. There is strong public opinion in Kazakhstan originally focused against nuclear weapons testing, but which may be directed at the upcoming safety review necessary to restart a 10-MW research reactor. This facility, which can produce radioactive isotopes, has been shut down since 1988 as a result of concerns about its seismic design. Radiation exposures and existing radiation contamination resulting from atmospheric weapons testing, which was halted in the early 1960s, remain of concern to the Kazakhstan public and also to their neighbours.

Initiating assistance efforts

There is a general weariness with fact-finding missions. One authority asserted that over 100 environmental missions had taken place over the past 2 years with essentially no practical assistance provided. To maintain credibility and interest in the recipient countries, it will be necessary for the joint UNDP-IAEA programme to initiate assistance efforts rapidly.

Practical assistance which could be commenced over the late 1993 and early 1994 time period would consist of the provision of some measurement and monitoring equipment. Additionally, a number of safety advisory missions and expert assistance activities to complement efforts for information exchange, such as national or regional workshops and scientific visits, could be carried out. To meet the need for up-to-date text books and journals, efforts could be made to set up libraries of key texts and to provide subscriptions to major scientific journals.

In line with this "demand driven" approach of the joint project, the assistance would primarily respond to the stated needs of the organizations visited. These short-term efforts and further follow-up work will lead to a fuller appreciation of the requirements of the three countries.

The IAEA does not have sufficient financial resources and specialized staff to provide all the support needed. Significant expert assistance will be required and extrabudgetary funds will be necessary. Promising contacts have already been made with several countries and there are possibilities of receiving some equipment on a cost-free basis. ❐

Improving the safety of WWER nuclear power plants: Focus on technical assistance in Central and Eastern Europe

At national and regional levels, nuclear specialists are working through IAEA-supported projects to upgrade plant safety levels

by Wiktor Zyszkowski

Energy balance in Central and Eastern Europe is based to a substantial degree on the use of nuclear energy. Nuclear's share of electricity production stands at about 20% in the Czech Republic, 25% in Ukraine, 32% in Bulgaria, 46% in Hungary, and 49% in the Slovak Republic. Reliable operation of nuclear power plants has been essential for the economic development of these countries.

Nuclear plants based upon Soviet technology, specifically pressurized-water reactors (PWRs) of the type known as WWERs, are dominant in Central and Eastern European countries. From the start, the approach to nuclear safety has been different for these plants, when compared with approaches for Western-designed PWRs. This resulted, in fact, in serious shortcomings of WWERs when compared with international practices. There was and remains a clear need for transfer of knowledge, particularly in the field of nuclear safety, to facilitate access to information on PWRs and related infrastructures. These needs extend to modern tools of safety assessment; quality assurance programmes; highly computerized instrumentation and control systems; and the use of robotics for in-service inspection, for example.

However, the situation should not be generalized. It strongly depends on the specific model of the nuclear power plant. These models start with the old WWER-440/230 (operating in Bulgaria, Slovak Republic and Ukraine), go to the more advanced WWER-440/213 (operating in the Czech Republic, Slovak Republic, Hungary, and Ukraine), and on up to the new generation of WWER-1000/320 (operating in Ukraine and Bulgaria, and being built in the Czech Republic). There is an understanding that a programme for safety improvements and technology transfer is required. However, this was difficult to launch in the past due to political and other constraints in the region. Nuclear specialists in the region were aware of the discrepancies between PWR and WWER technologies and looked for possibilities to improve the situation. In the early 1980s, they asked the IAEA for technical assistance.

This article reports on the IAEA's technical assistance projects that have been initiated over the past years to upgrade the safety levels of WWER-type nuclear plants. It also looks at the work ahead, specifically at activities planned into the mid-1990s.

Launching the projects

From early on, the provision of technical assistance, in particular through the IAEA's technical co-operation programme, represented an important avenue for transferring knowledge and technology. Though possibilities in the early 1980s were limited for WWER-type reactors, they have since expanded. What has emerged is a highly effective mechanism of regional co-operation that has become essential for countries interested in strengthening their national capabilities in the nuclear power sector.

In 1984, under an early regional technical co-operation project, access to the IAEA's computer system was provided. This opened the possibility of using the most advanced thermo-hydraulic computer code at that time. Standard

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problem exercises were formulated for calculations on loss-of-coolant accidents that created possibilities for regional co-operation and comparison of results with those obtained by Western specialists. An experimental facility constructed at KFKI, Budapest, was a source of experimental data on which the comparison was based. Bulgaria, the former Czechoslovakia, Hungary, and Poland benefitted from the exercises, as did many other countries in the region.

In 1988 a follow-up project started which focused on safety analyses of the WWER-type reactors. The activity was extended to other fields, including maintenance, radioactive waste management, regulatory infrastructure, and various safety review missions to WWER-type nuclear power plants.

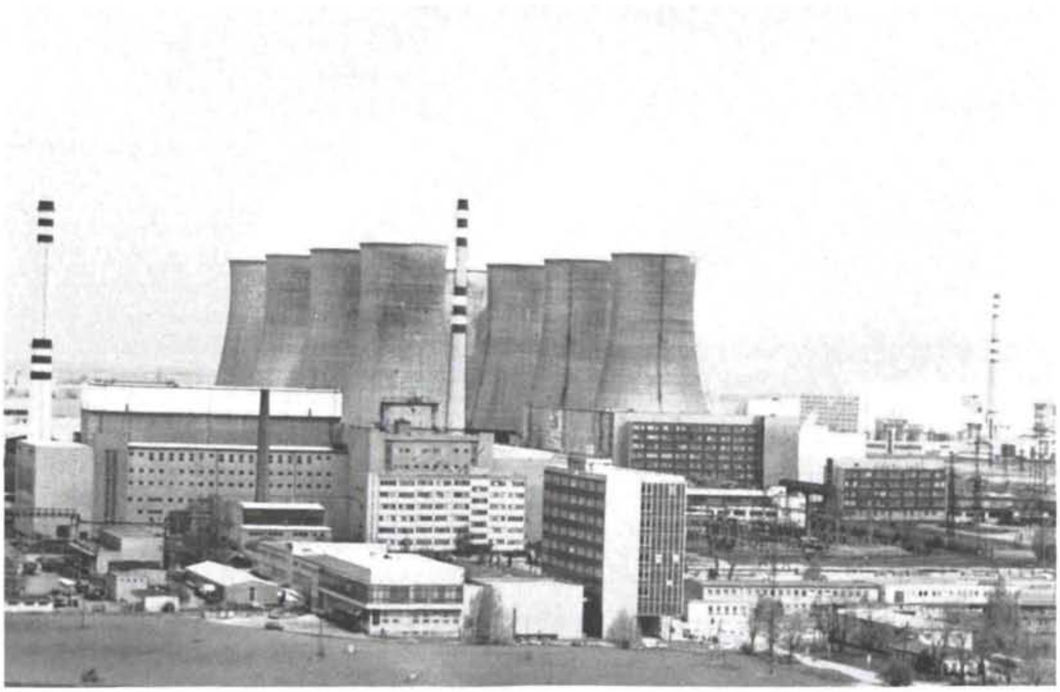
Strengthening national capabilities through regional co-operation

A long-term objective of technical assistance to countries with WWER plants is the strengthening of their national capabilities. This entails helping countries to create an infrastructure for independently evaluating and assessing the plants. Several regional projects have become the main vehicles for this, involving Bulgaria, Czech Republic, Slovak Republic, Hungary, Poland, and Ukraine.

Safety assessment. WWER-type reactors in Central and Eastern European countries have been the subject of criticism as far as overall safety is concerned. Consequently, there is a need for comprehensive assessment and systematic study of their status.

The new WWER-440/213 units incorporate higher structural safety margins in the barriers for preventing radioactive releases that approach Western standards. These units can challenge questions about the extent to which a plant's inherent safety can compensate for certain deficiencies in safety systems. Under an IAEA regional project, an internationally accepted method of assessment using the most advanced computer safety codes is being developed. Related documentation for assessing the actual safety level of the Bohunice nuclear power plant, using the WWER-440/213 as the reference plant, also is being provided.

Specifically, the project focuses on safety reassessment by means of up-to-date methods and techniques for summarizing all available information on the design philosophy; summarizing experimental results supporting the design; evaluating operational results from the point of view of plant performance and safety; establishing accident analysis methodologies for both design basis accidents (DBAs) and severe accidents beyond DBAs; updating DBA analyses as reference analyses for the production of safety reports, operating instructions, and technical specifications (including external events); extending analyses beyond DBA and severe accident situations with special attention to accident management considerations; assessing safety levels and safety margins in the light of new safety requirements; determining priorities for safety enhancement and backfitting (if neces-



The Bohunice nuclear plant in the Slovak Republic.

sary); and providing the scientific and technical basis for decision-making by regulatory organizations.

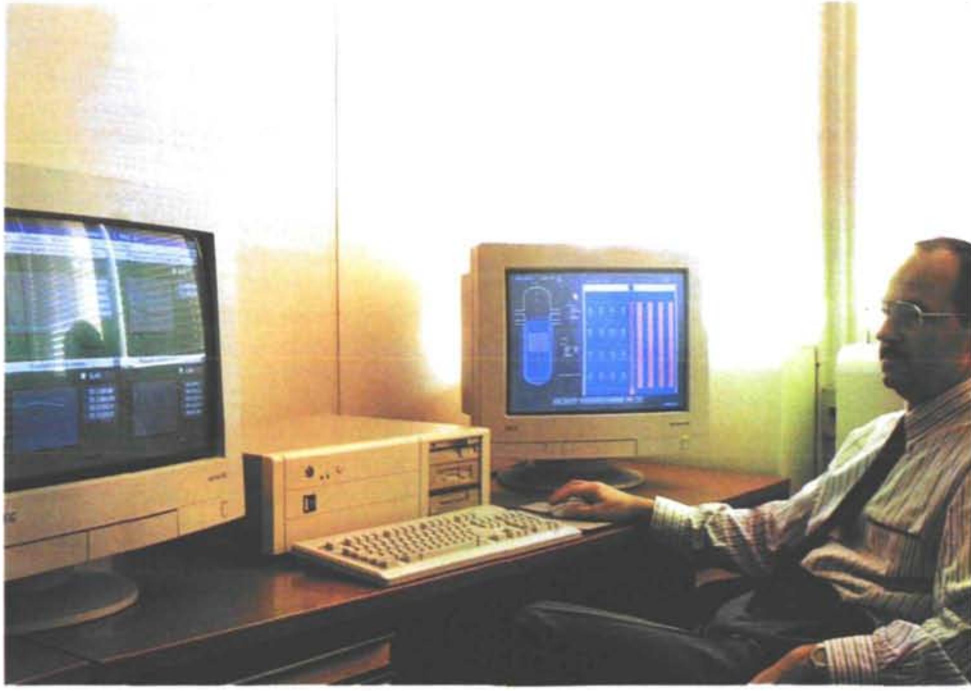
Specific tasks have been formulated and distributed among the participants, which include 19 institutions and more than 100 national specialists. IAEA assistance consists of the provision of computer codes, advanced computer techniques, expertise, and organization of workshops, working groups, and other meetings, as well as co-ordination of the safety assessment activities. Simultaneously, comprehensive national programmes financed from national resources have been launched and benefit from the methodology and results achieved under the regional project.

Despite continuous internal quality assurance, an independent peer review by an internationally recognized specialized organization is a necessary condition for acceptance of the results. Such a review process was started in 1992 and received support from Tractabel in Belgium, Tecnatom in Spain, and the Commission of the European Communities (CEC) in Brussels. The target date for completion is mid-1994. The results will constitute essential guidance on the methodology for preparation of plant-specific safety assessments by national specialists.

One positive example of this regional co-operation is the development of a severe accident simulation trainer for the Bohunice WWER-440/213 plant in the Slovak Republic. It is being developed by an international team of specialists with close co-operation with Risk Management Associates, Inc., in the United States.

Probabilistic safety assessment (PSA). Since the mid-1970s, the probabilistic approach to safety analysis has proved to be an extremely useful complement to the standard, deterministic type of analysis. The approach provides both operators and regulators with additional insights into the safety of nuclear reactors. Consequently, most countries having nuclear power plants have developed a plant-specific PSA for every operating reactor. A broad spectrum of applications that have been demonstrated includes the evaluation/improvement of design and procedures; optimization of technical specifications and maintenance activities; PSA-based regulatory inspection; and assessment of operational experience. Benefits from the use of PSA have also been recognized in all Central and Eastern European countries and large efforts have been made to implement this technique.

A regional programme initiated by the IAEA in 1988 was the first international activity directed towards practical implementation of PSA in countries operating WWER power plants. Initially, the programme was structured to provide training/education of PSA practitioners and to assist in development of generic Level-1 PSA for a WWER reactor. This was supposed to be a basis for development of plant specific Level-1 PSAs at the later stage. Each participating country (including Bulgaria, the former Czechoslovakia, Hungary, and Poland; with the former German Democratic Republic and Soviet Union as observers) was to perform accident sequence modelling for a limited number of initiating events. The Agency provided expertise,



Under an IAEA regional project, a severe accident simulation trainer known as MELSIM is being developed for operators of Russian-designed WWER-440/213 nuclear plants. The trainer is a personal computer-based system that also serves to evaluate accident management strategies and to assess complex interfaces between emergency operating procedures and accident management guidelines. The trainer utilizes several computers working simultaneously on different areas of the simulation. Detailed plant operation displays, portions of which are shown here, are provided on colour monitor screens which show changing plant conditions.

guidance, and co-ordination of the work mainly through a number of workshops centered on selected methodological issues.

The project's main achievement in the first period (1988-91) was the initiation of actual application of PSA methodology for safety assessment of WWER plants. This encompassed adopting and comprehending the methodology for Level-1 PSA and familiarity with computer software. Specialized PSA teams with practical experience now have been consolidated in all participating countries. As a consequence of this IAEA project and growing awareness of nuclear safety issues, comprehensive national PSA programmes were initiated in all countries operating WWER plants. Plant-specific PSA studies are being done or planned for practically every plant in the region. By 1994 PSA Level-1 studies for all types of WWER units (440/230, 440/213 and WWER-1000) will have been completed.

Responding to the new status of national PSA programmes, the emphasis of the IAEA's project is changing. For the period 1993-94 the assistance is centred on advanced PSA methodology; use of PSA results; and assurance of high-quality PSA through independent reviews.

The project has achieved important results, especially in areas of immediate interest. A "data exchange" workshop held at the Paks nuclear plant in Hungary in June 1993, for example, brought together PSA teams and WWER operators from all participating countries. The workshop was used to finalize preparation of a technical document describing data collection activities and providing numerous plant-specific data sets.

A number of previously prepared documents already are being used in PSA projects for WWER reactors. One contains lists of separate generic initiating events specifically developed for the WWER-440 and 1000 models and a unique classification of more than 350 reactor-years of operational experience. Due to different design and operational practices, Western PWR operational experience is generally not appropriate for PSAs on WWERs. The project facilitated collection and analysis of operational experience on all types of WWERs.

Another important area where positive results are visible is PSA reviews. An independent review of ongoing work was performed for the PSAs of the Kozloduy-3 plant in Bulgaria, Bohunice-1 in the Slovak Republic, and Kola in Russia. An end-of-project review for the PSA of Hungary's Paks plant has just been completed.

Significant activities in PSA application are expected in 1994 and beyond. The bulk of activities is expected during 1994 when initial Level-2 PSAs, external analyses, and shutdown risk studies are to be performed. The work will further support PSA applications, which are making significant inroads in countries with WWER plants in areas of regulation and operational safety. At the Dukovany plant in the Czech Republic, a risk monitoring system is being developed for completion in early 1994, and it is expected that PSA will be used for decisions on priorities for backfitting options. Other activities, being considered for implementation after 1994, concern the characterization of the source term (amount of radioactive materials potentially released in an accident) for WWER units, as a basis for efficient accident management and emergency preparedness.

Plant maintenance and service

Maintenance, in-service inspection, and quality assurance are considered the weak points in the management of WWER technology. They have been included in IAEA technical co-operation projects under both regional and national programmes.

The first issue addressed in 1990 was in-service inspection (ISI) of the steam generators at the Kozloduy nuclear power plant. A specialized company from the Institute za Elektroprivredu in Zagreb performed the first eddy-current inspection. The result was a warning that such an inspection must be repeated for other plants. As a consequence, a technical assistance programme was launched in support of efforts undertaken by IAEA Member States operating WWER-type reactors to develop adequate national infrastructures and systems for such inspections. The IAEA has provided assistance through on-the-job training, workshops, and expert services. Emphasis has been on establishment of inspection requirements, basic equipment criteria, and general staffing requirements; evaluation of local capabilities; definition of the implementation approach; building up of basic in-service inspection capability; establishment of quality assurance programmes; and establishment of the in-service inspection programme. Also, through an extrabudgetary contribution from Spain, the technical specifications and basic design of in-service inspection equipment has been provided to the countries participating in this project.

Inspections are directed at particular components including the reactor pressure vessel, steam generators and primary circuit piping, pumps, valves, and pressurizers. Consequently, the project's workshops and on-the-job training emphasized practical approaches to examination of these components. Inspection techniques for eddy-current testing and other forms of non-destructive testing (ultrasonic methods), as well as steam generator tube plugging, were presented in detail. Additionally, "first-hand" studies were arranged by taking the participants to nuclear power plants during their scheduled maintenance. National projects for Bulgaria and Hungary further contributed to the upgrading of their capabilities for performing inspections of main components for their plants.

As follow-up to the ISI project, the IAEA initiated a regional project centred on plant maintenance and service activities. The project was financed both by the IAEA's regular budget and extrabudgetary contributions form the USA. It resulted in the transfer of knowledge on modern maintenance methods and technology through various avenues. They included technical exchanges, workshops, and a risk-based (PSA) management programme. This programme was designed so that it could be used as the basis for day-to-day operational and maintenance activities at these plants, and for short- and long-term assessment and prioritization of safety-related needs or improvements.

Radioactive waste management

Countries operating WWER-type nuclear power plants have encountered difficulties originating from shortcomings in national strategies and regulations, and in the available technology, in the field of radioactive waste management. One IAEA regional project, launched in 1991, is directed at improving the safety and effectiveness of radioactive waste management practices at WWER plants. Because the accumulated experience and level of development differs from country to country, regional co-operation is recognized as very effective for identifying common problems, sharing experience, and for recommending improvements on waste management that can be considered and implemented.

The list of general issues requiring corrective actions and improvements is as follows:

- legislation in the field of radioactive waste management;
- overproduction of waste at nuclear power plants;
- excessive leakage from equipment;
- build-up of untreated evaporator concentrates;
- inadequate facilities for volume reduction and conditioning; and
- absence of guidance on exemption limits for very low level wastes.

The project's first phase covered activities during 1991-92. Results have been reported in an IAEA technical document, *Radioactive Waste Management of WWER-type Reactors*, issued in 1993. The report identifies waste management problems at power plants with WWER reactors, and describes plans for regional co-operation among countries having WWER-type reactors in operation and for the emulation of good practices being followed at Western nuclear plants.

Basic elements of integrated systems for the safe and efficient management of radioactive wastes also were the topic of a regional training course in Slovakia in 1992. The course was attended by 23 participants from Member States in the region.

The project's next phase, over the 1993-94 period, is directed at two main tasks:

- providing assistance to participating countries in evaluation and improvement of existing legislation of the structure of regulatory bodies, of licensing principles, and of requirements for radioactive waste management at nuclear power plants; and
- performing a comparative evaluation of waste management systems of nuclear plants with WWER-type reactors, as well as providing recommendations for improving these systems.

Expertise from countries such as Finland, France, Sweden, the United Kingdom and the United States has been provided from the start of this regional project.

Countries in Central and Eastern Europe operating WWER-type reactors also have asked the IAEA for advice regarding spent-fuel storage, an area of pressing concern. Previously, spent fuel from these countries was returned to the former Soviet Union for reprocessing. However, this solution for all spent fuel requirements can no longer be guaranteed in light of the region's political and economic developments.

National projects and other activities

A number of technical projects have been included in the IAEA's WWER programme which have contributed to improvements in the nuclear energy sector. Essential roles have been played by nuclear plant safety reviews, namely through IAEA services known as Operational Safety Review Teams (OSARTs) and Assessment of Safety Significant Events Teams (ASSETs). All countries with WWER-type reactors have hosted such missions, through which more knowledge about the plants has been acquired.

In 1991, an OSART mission to Kozloduy in Bulgaria, and subsequent follow-up visits, advised the regulatory body on the operational safety of two units, among other matters. Bulgarian specialists also participated as observers in OSART missions to nuclear plants in Koeberg in South Africa, Grafenrheinfeld in Germany, and Fessenheim in France. OSART and follow-up missions also have gone to Paks in Hungary and Temelin in the Czech Republic. In parallel, a seminar on ASSET methodology was organized for these countries. In Bulgaria a series of ASSET missions dealt with the management of safety significant incidents at the four WWER 440/230 units at the Kozloduy nuclear power station; operational safety performance; training of operators and regulators; assisting plant management to implement ASSET recommendations; and assessing progress in the prevention of incidents. In addition, workshops have been held on the use of the International Nuclear Event Scale (INES), which standardizes the reporting of incidents at nuclear power plants.

These safety missions should be considered not only as a source of information on WWER-type reactors. They also serve as an important mechanism for transferring knowledge on safety culture and modern practices of nuclear plant operations to countries of the region.

Other activities have been arranged to complement regional projects. Designed to address specific national problems, these activities are related to:

- quality assurance and ISI for nuclear power plants (Bulgaria, Czech Republic, Slovak Republic, Hungary, Poland);
- site and seismic safety (Bulgaria, Czech and Slovak Republics);
- nuclear safety and radiation protection (Bulgaria, Hungary, Ukraine);
- radioactive waste management and spent fuel storage technology (Bulgaria, Hungary, Poland);
- management and analysis of severe accidents (Czech and Slovak Republics, Hungary);
- measurements of noise thermometry and burnable absorbers in WWER-type reactors (Bulgaria, Czech and Slovak Republics);
- national training of nuclear specialists (Hungary); and
- strengthening national regulatory capabilities (Czech and Slovak Republics).

While these activites mainly focus on transfer of knowledge, equipment is supplied in some cases. Modern ISI equipment designed and manufactured by Tecnatom in Spain, for example, was made available for the inspection of the reactor pressure vessels in Bulgaria and Hungary. This further opened possibilities for training of specialists on a regional basis. Technology also was provided for the management of radioactive waste at the Kozloduy plant in Bulgaria. This has significiantly contributed to the development of scientifically based release limits which are being implemented now.

These national projects are accompanied by a very comprehensive programme for developing human resources through training in specific subjects of nuclear safety and nuclear engineering. More than 100 scientific fellows from countries in the region have been trained during the last 10 years in fields related to WWERs. Recently consideration has been given to supporting a regional training centre in maintenance. This centre would complement an existing one for nuclear power plant operators.

Complementary efforts

The IAEA's technical assistance programme on WWER-type reactors is part of a wide range of activities being carried out by the IAEA and other organizations in countries of the region in the nuclear power sector. The programme is playing an important complementary role, despite relatively limited financial resources.

In particular, it is:

- contributing to the improvement of nuclear safety in the nuclear power sector in Central and Eastern European countries;
- strengthening and/or developing national capabilities in performing safety analysis and independent safety assessment of each country's nuclear power plants;
- promoting international co-operation between countries having similar circumstances and problems in areas of nuclear power;
- consolidating expertise with respect to the development of human resources;
- transferring knowledge from countries with advanced experience and equipment for nuclear safety (hardware and software) to the region;
- improving communication and the base of worldwide knowledge on WWERs and their safety;
- providing international expertise and advice on particular safety issues; and
- creating a mechanism for international co-operation and channelling the transfer of knowledge and technology to the operators of WWER-type reactors. ❐

The next generation of nuclear power plants and beyond: Raising the level of ambition

A common goal is driving the development of advanced reactors

by
C.A. Goetzmann, L. Kabanov, and J. Kupitz

Practically all countries with civilian nuclear power programmes are developing improved versions of currently existing nuclear power plants for implementation before the turn of the century. They are called evolutionary plants, as they have incorporated improvements in a step-by-step fashion, drawing on the accumulated experience of existing nuclear plants, which together have recorded more than 6000 reactor-years of operation. The targeted improvements concern many aspects, from design, construction and operation, to safety and economics.

In particular, enhancing safety even beyond the impressive level that has already been achieved for the vast majority of existing plants is a common goal. An impartial comparison with alternative means of economical large-scale electricity production — as was presented at the Senior Expert Symposium in Helsinki in 1991 — shows nuclear to be significantly superior in terms of minimizing the impact on human life and on the environment. Although this fact is not new, it needs reiteration and appropriate publicity to assure the unsure public, very often confused by sensationalistic media, to reassure politicians and, somewhat surprisingly so, also to reassure some of the people with doubts inside the nuclear community.

In the context of this article, the term safety stands for the result of accomplishing by technical means the following two essential tasks: Firstly, to design, build, operate, and maintain the reactor plant in such a way that neither equipment failures, nor operator errors, nor external events such as earthquakes, can lead to overheating of the nuclear fuel and, as a consequence, to a subsequent release of dangerous amounts of radioactivity to the reactor cooling system. Secondly, to provide and maintain a strong and leak-tight containment shell around the reactor cooling system in order to retain the bulk of radioactivity which might be released in an accident sequence that is not terminated within the reactor plant itself, as it should be in compliance with the first task.

What is significant is that nearly all currently operating reactors are to a high degree in accordance with internationally accepted safety principles. To achieve this status, many older plants had to be modernized with additional equipment in the plant proper, with ergonomically improved control panels, and with improved operating procedures, the latter in conjunction with intensified operator training.

A respective large impetus came from the very thorough examination of the serious accident at the Three Mile Island (TMI) plant in 1979. Other lessons have been drawn from the ever increasing operating experience in the world. This experience is openly being exchanged at an international level between operators, designers, research and development institutions, and regulatory organizations. The lessons learned represent a significant input to the designs of the next generation of evolutionary nuclear power plants. It can be expected that this input will enhance their safety even further. This is because the modernization measures mentioned before can be tailored right into the design. This is far more effective than backfitting existing plants.

For assessing or "measuring" safety improvements, designers employ sophisticated methods which are also being used in other industries, such as the aerospace industry. One method is known as probabilistic safety assessment (PSA). It basically describes, or models, the entire power plant in terms of interacting components, systems, functions and operator ac-

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tions. It identifies the probability that an initiating failure or error is not being stopped by one of the layers of defense from further propagating into a severe fuel damage. This is done for a large number of initiating events and results in a single cumulative figure for the probability of a severe core damage per reactor and year. This characteristic figure has significantly decreased from typically about one in-a-thousand before the TMI-accident to well below one-in-ten thousand today. The goal for the next generation of nuclear plants is another decrease by at least a factor of ten. Most designers strive for a figure of one-in-a-million.

Apart from evaluating these figures for comparing the effectiveness of different design options for meeting the defense-in-depth principle, such probabilistic analyses help, and force, the designer to identify the weak points in the design. They clearly indicate where improvements are needed, and allow the selection of the best engineered countermeasures. Achieved safety levels are very high and further improvements can be expected. There is thus no reason not to continue for a long time to come with the evolutionary plants that are currently under construction or in various stages of planning.

Yet, in spite of nuclear power's highly satisfactory record, there is an intensive debate among the experts on to how to do better. Not because the achieved safety is inadequate, but rather in the quest of excellence. In particular, by doing better still, some hope to make significant progress in regaining public acceptance.

Two broad directions can be identified. The first one stresses the desirability, or even necessity, of continuing the evolutionary path, primarily since the ever increasing experience with existing plants provides a solid foundation for the future. Enhancing safety even further, where considered necessary, could be done best within that framework. The other line of thinking argues instead for a novel approach with more innovative reactor concepts, particularly if the use of nuclear power is to be substantially increased. Both views will be briefly discussed.

The evolutionary approach

Within the context of enhancing the safety for the next generation of advanced water-cooled reactors, improved protection is being sought against the consequences of a severe accident, such as melting of the fuel. Investigating severe accident phenomena is a major worldwide research and development task. It aims to more precisely identify all potential challenges to the desired containment performance and to eliminate by design measures any weak points that may be found. The ultimate objective of these activities is to be able to demonstrate that, from a technical point of view, no emergency measures, such as evacuation, would be needed to protect the general public even after a severe accident inside the nuclear power plant. The impact of the accident is to be limited to the site itself so that the life of the population on the outside is not disrupted.

Casting this objective into an internationally accepted recommendation is one of the major activities of the IAEA. The principles laid down by the International Nuclear Safety Advisory Group (INSAG), an advisory body to the IAEA's Director General, would be very well suited for this purpose. In essence, the technical safety objective stated in the report known as INSAG-3* would have to be expanded to deal also with severe accidents beyond the so-called design basis accidents. Certain modifications would in addition be needed for the principles concerning the containment, with significant work still outstanding for defining the technical implications and consequences.

The innovative approaches

Many proponents for innovative design approaches for future reactors subscribe to another view. They argue that, while the safety of present and future evolutionary reactors is acceptable, its implementation, and maintenance over time, requires technical systems that are functionally too complex and put an undesirably high burden on the operator. They call for significantly simpler plants whose ultimate safety depends much less — and in the extreme not at all — on the proper functioning of engineered safety systems and on proper operator responses, as compared with the evolutionary plants. Some proponents also believe that with such innovative reactor concepts public acceptance of nuclear power could be significantly improved.

It is further argued that the need for innovative approaches becomes much more pressing if nuclear power is to be substantially increased in the future, expanding into many regions of the world which today have little, or no experience with that technology. Is it affordable, the question is being asked, to establish, assure, and maintain the exacting technological and human resources that are necessary for designing, licensing, building, operating, and maintaining

***Basic Safety Principles for Nuclear Power Plants*, (INSAG-3), IAEA Safety Series No. 75, Vienna (1988).

the evolutionary descendants of current reactors in a way that the desired safety is uniformly maintained all over the world for a long time to come? Or, to put it differently, can this task be made easier with innovative reactor concepts? This is one line of reasoning for innovative approaches. Another one asserts that it may be possible to *a priori* "design out" the possibility, albeit very unlikely, of a severe core damage in the first place, ultimately resulting in a much improved public acceptance of nuclear power.

Simplification, and making the reactor plant more resistant to equipment failures and operator errors, is also an explicit objective for the evolutionary plants. Consequently, the controversy between evolution and innovation is less about the goal of safety, but rather about the means of reaching it, and is thus highly technical in nature.

A large number of innovative concepts have been under discussion for many years. Some are based on light-water reactor technology, others are derived from the development of gas- or liquid metal-cooled reactors. As to maturity, they range from pre-conceptual to already very detailed and backed by considerable specific research and development. The prevailing opinion, however, is that each concept would need an appropriate industrial-size prototype before it could be considered an option for expanding nuclear power. Some of the concepts may even need *a priori* feasibility tests.

To the extent that they are being proposed on grounds of improved safety, all concepts attempt to fulfill two major safety objectives. One is to reduce, or even eliminate, the necessity for correct operator actions when controlling major accidents. The other is to eliminate the need of forced coolant flow for removing the residual heat that all reactor fuel elements still release after the nuclear chain reaction has been terminated. Forced flow, in this context, means no reliance on rotating machinery, such as pumps, or the energy needed for driving them. Some of the concepts try to accomplish this "passive residual heat removal", as it is often called, also for conditions when the reactor coolant system has been afflicted by an accidental leak.

Although differing in individual solutions, all innovative concepts try to engineer protection against accidents into the design to the maximum extent possible. No initiating event, e.g. loss of electrical power due to a severe thunder storm, should escalate into endangering the integrity of the fuel elements. Of the three imperatives enunciated by INSAG — namely controlling the reactor power, cooling the fuel, and confining the radioactivity within the appropriate barriers — the innovative concepts stress the first two.

They thus place maximum emphasis on the preventive level in line with defense-in-depth principles, and with INSAG's principle that "principal emphasis is placed on the primary means of achieving safety, which is the prevention of accidents, particularly any which could cause severe core damage".

The innovative concepts can thus hardly be criticized on grounds that they would move away from established principles, an important strategical aspect. Quite the contrary. The price in terms of capital costs does seem to be high, though, and relief must be sought and granted somewhere else in the design by relaxing certain engineering requirements.

Innovative concepts strive for less "safety culture" than is presently the case for established reactors since in emergencies the response of the operator, or the function of certain systems in some cases, is not decisive for adequate protection. It is somewhat surprising that error, inaction, or even maliciousness of the operator are considered as far more dangerous to safety than equipment failures. Two conclusions may be drawn from this. The first one would be a tribute to defense-in-depth. Redundancy, diversity, and physical separation, in conjunction with the operator's dedication to safety ("safety culture"), are obviously proven and acknowledged in their effectiveness and value. The second conclusion is as follows: If system simplification and man-machine interface improvements are implemented with an even higher degree of automation — an explicit objective for the evolutionary plants — then the concerns about operators could be considered greatly reduced. In other words, much of what is a major driving force for the innovative concepts will also be accomplished with the evolutionary designs.

Clarification and harmonization

One goal expressed by some proponents for innovative reactors is to come up with designs that can be called "deterministically safe". This is to mean that it would be desirable that adequate safety to the public could be demonstrated without emphasizing probabilistic arguments. As long as this is not understood as "nothing at all can happen under all circumstances", a position very difficult to defend, the antipodes of evolutionary and innovative approaches can probably be united. Both ultimately aim at demonstrating that accidents with severe consequences to the public can be excluded. The means for achieving this objective are deterministic in either case. The evolutionary designs do this by providing staggered layers of protection and mitigation within the defense-in-depth approach. The innovative ones seek specific features such as large temporary heat sinks and paths for dissipating decay heat in a passive manner, as it is sometimes called.

The term "deterministically safe" reactors can thus accommodate inherent, passive, active, and other features for achieving the ultimate objective of no severe consequences for the public. Much of the confusion that goes with terms such as passive, inherent or forgiving, wrongly applied when referring to the total plant, but entirely correct with reference to specific systems or functions would disappear. It would also be much easier for the public — which really only wants to know whether it can be affected by an accident or not, rather than having to decide on technical details for which it has little background.

Probability analyses would still be necessary to find out which conceivable accident sequences need deterministic protection, both for evolutionary and innovative plants. However, it must be clearly stated that "deterministically safe" ultimately only means that severe consequences have such a low probability that they should be accepted like any other major catastrophe.

Respective probabilities are sufficiently low for future evolutionary plants; innovative ones need not do better. Keeping the above qualification in mind, both types could be called deterministically safe. To the extent that the public is concerned, there is no dilemma left and an opposing view cannot be upheld.

The discussion is one that has to be done inside the nuclear community among specialists. Its thrust has to be directed away from which concept is the safest, irrespective of cost, to which concept leads to the lowest generating cost for a commonly accepted safety level.

Motives and constraints for the future

Motives. Innovative concepts cannot be primarily justified for safety reasons. Rather, they have to meet other needs. Probably the most significant ones concern their potential for helping to meet the world's growing energy consumption, and for helping to reduce the greenhouse problem at the same time.

Simplification is one major objective of the next generation of evolutionary plants for the industrialized countries. How much stronger would this objective weigh for the less developed countries that would have "to go nuclear" in the above context? It is almost inconceivable that industrialized nations could accommodate most of the estimated five- to ten-fold capacity increase over what is currently installed. The *a priori* requirements of adequate safety culture and adequate infrastructure are severe impediments against substantially increasing the use of nuclear power the world over. An evaluation of associated costs is greatly needed as it will influence the necessary choices. If, as suspected, the costs are high, then designing around the problem may very well be an endeavor that deserves careful consideration. However, if a solution for a "low safety culture concept" could be found, it will lead to two problems. First, how could it coexist in the long run with the traditional approaches? Could regulators live with a two-class reactor population? Second, will there be customers who would acknowledge needing such a special concept because they can't do any better? Will they not feel they are being discriminated against?

Achieving a desired safety level always rests on the proper combination of three key qualities: that of the plant proper, that of the available infrastructure, e.g. grid, and that of adequately trained operators. If the latter two are weak, then the machine has to make up for it. If a reactor could be found that does precisely this, what are the consequences if it were re-imported to the industrialized countries? Would it mean that in this case there would be a new standard that regulators would make mandatory?

Constraints. However, there are severe constraints that stand in the way of a rapid expansion of nuclear power, no matter whether they are based on evolution or innovation. Neglecting issues of favourable economics, ultimate waste disposal, treatment of currently unsatisfactory plants, and non-proliferation, the most important constraints comprise, almost as criteria, the following: The public must be made aware of, and must understand, the benefits of nuclear power and thereupon accept its desirability, or even its necessity. The public in industrialized countries must likewise understand that expanding nuclear into developing countries will need extraordinary financial efforts. Thirdly, promotion of innovative concepts must not be done in a way that questions what is being planned for the near future with the evolutionary concepts. If that is not understood, the possibility arises that the nuclear option will be lost altogether.

Overcoming these constraints is a formidable task. It would appear desirable to develop an appropriate master plan which defines in greater detail which sub-tasks have to be accomplished in what manner so as to foster a vigorous nuclear renaissance and expansion after the first decade of the next century. The IAEA would be the ideal institution for developing such a plan. ❐

Global levels of radiation exposure: Latest international findings

The 1993 UNSCEAR report reconfirms that peaceful nuclear activities account for a small fraction of total exposures

by
Abel J. González

The radiation exposure of the world population has recently been reviewed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). In its 1993 report to the UN General Assembly, UNSCEAR has reconfirmed that the normal operation of all peaceful nuclear installations contributes insignificantly to the global exposure to radiation. All peaceful nuclear activities taken together deliver a global exposure equivalent to just a few days of exposure to natural radiation sources. Even if all the nuclear accidents that have occurred to date are considered (Chernobyl included), the additional exposure would be equivalent to only around 20 days of natural exposure. *(See table below.)*

According to UNSCEAR, the military uses of nuclear energy have committed the world population to most of the radiation exposure caused by human activities. Exposure that has been and will continue to be delivered by all atmospheric explosions that have been carried out for the testing of nuclear weapons — not including other related activities such as the production of weapon materials or other military activities — is equivalent to 2.3 years of exposure to natural sources. In second place is exposure to natural sources itself. In a distant third place is medical exposures: one year of medical exposures to patients is responsible — on average — for the equivalent of 90 additional days of exposure of the world population to natural radiation. The annual occupational exposure to workers, averaged over the world population, is equivalent to few additional hours of exposure to natural radiation sources.

There are wide differences in the exposures incurred by particular individuals, but UNSCEAR is mainly concerned with the global picture of radiation exposures. *(See box.)* The committee's report can be construed to imply where the priorities should lie for the global protection of human beings against radiation. The peaceful uses of nuclear power are far down the list of concerns. Public perceptions are quite different, but this is frequently the case in relation to radiation exposure.

As is customary, UNSCEAR has also made a detailed compilation of world knowledge on the biological effects of radiation. It reconfirms deoxyribonucleic acid (DNA) as vulnerable to radiation. The report discusses the effects of changes in the cell genetic code, which are presumed to be induced by radiation exposure. Radiation exposure may either kill cells and produce the clinically detectable deterministic effects (sterility, opacities of the lens of the eye, depression of blood formation, erythema), which

Exposure to man-made sources of radiation expressed as equivalent periods of exposure to natural sources of radiation

Source	Basis	Equivalent period of exposure to natural sources
Medical exposures	One year of practice at the current rate	90 days
Nuclear weapons tests	Terminated practice	2.3 years
Nuclear power (normal operation)	Total practice to date One year of practice at the current rate	10 days 1 day
Severe accidents	Events to date	20 days
Occupational exposures	One year of practice at the current rate	8 hours
Exposure to natural sources	Global average	(1 year)

Dr González is Deputy Director of the IAEA Division of Nuclear Safety. The UNSCEAR report is called *Sources and Effects of Ionizing Radiation*, UNSCEAR 1993 Report to the General Assembly (48th Session, Suppl No. 46 (A/48/46)), UN Publication Sales No. E.94.IX.2, United Nations, New York (1993).

Committed collective exposures to the public from nuclear power production (normalized per unit of energy produced and expressed as percentage)

Source	Percentage normalized per unit energy produced
Local and regional component	
Mining, milling and tailings	0.7%
Fuel fabrication	nil
Reactor operation	0.6%
Reprocessing	0.1%
Transport	0.05%
Global component (including solid waste disposal)	
Mining, milling and tailings (releases over 10 000 years)	74.0 % —
Reactor operation	0.25%
Globally dispersed radionuclides mainly from reprocessing and solid waste disposal	24.3%
Total (rounded)	100.0%

Collective exposure committed to the world population by a 50-year period of operation for continuing practices or by single events from 1945 to 1992 (as a percentage)

Source	Basis of commitment	Percentage	
Natural sources	Current rate for 50 years		76.58%
Medical exposure:	Current rate for 50 years		
Diagnosis			10.68%
Treatment			8.83%
Atmospheric nuclear weapons tests	Completed practice		3.53%
Nuclear power	Total practice to date	0.04%	
	Current rate for 50 years	0.20%	
	Total:		0.24%
Severe accidents	Events to date		0.07%
Occupational exposure:	Current rate for 50 years		
Medical		0.005%	
Nuclear power		0.01%	
Industrial uses		0.003%	
Defense activities		0.001%	
Non-uranium mining		0.05%	
Sub-total (occupational exposures)			0.07%
Total			100.0%

Annual exposures from natural sources

Source of exposure	Annual effective dose (mSv)	
	Typical	Elevated*
Cosmic rays	0.39	2.0
Terrestrial gamma rays	0.46	4.3
Radionuclides in the body (except radon)	0.23	0.6
Radon and its decay products	1.30	10
Total (rounded)	2.40	—

* The elevated values are for large regions; even higher values occur more locally.

Nuclear energy and radiation exposure

From the minute contribution of nuclear power to the committed (i.e. projected) exposure of the world population, the normal operation of nuclear power plants, in turn, accounts for just a fraction, the UNSCEAR report states.

The local and regional component of this exposure is a minor contribution to the total exposure, at around 1.5%. Of this, reactor operations account for less than half, and uranium mining, milling and tailings account for half. The major contributor is the so-called global component, which is dominated by the presumed effect of releases of long-lived radioactive materials. Radioactive releases due to mining and mill tailings — over the projected period of 10 000 years — are responsible for most of this global exposure, namely 75%. Radionuclides expected to be disposed of from reprocessing and solid waste disposal account for the other 25% globally. The global component from reactor operations is negligible in comparison.

It is important to note that the numbers in the tables shown here are derived from collective totals. They result from theoretical models that predict the summation of all individual exposures caused by an activity. However, individual exposures can vary widely. The fallout of radioactive materials due to nuclear weapon testing, for instance, has committed the world population to a roughly homogeneous exposure. The world average of occupational exposures, on the other hand, has little significance for the individual since only the relatively few workers exposed to radiation make up the sum. The individual exposures due to the normal operation of nuclear power also can be considered rather homogeneous because of the predominance of the global component; however, nuclear accidents have significantly delivered exposure to only a small fraction of the world population, and the global average should be treated with care. For the medical exposures, radiodiagnosis is relatively homogeneous throughout the world (most people have undergone radiographic analysis at some time in their lives). However, exposure to radiation for therapeutic purposes is incurred only by patients undergoing radiation treatment, who constitute a relatively small fraction of the population.

Even for natural exposures, the individual differences can be enormous — orders of magnitude between a person living in an uninsulated, unventilated house in a radon prone area having high levels of background radiation and a person living in a tropical area having low background levels of radioactivity.

Note: In the table at left, exposures are expressed in millisievert (mSv), i.e. thousandths of the International unit of exposure, the Sievert. One mSv is the currently recommended annual dose limit for members of the public for exposures from practices under regulatory control.

occurs only at high doses, or may transform cells and induce an increase of the epidemiologically-attributable stochastic effects (cancer induction or hereditary effects) to radiation. The biological annexes to the report concentrate on the mechanisms of radiation oncogenesis, the influence of dose and dose rate on stochastic effects, hereditary effects, radiation effects on the developing human brain and late deterministic effects in children.

All told, UNSCEAR reconfirms that:

- Clinically attributable deterministic effects occur only if a high threshold dose is exceeded. (These effects are easily preventable, since the threshold dose is much higher than the regulatory limits of radiation exposure.)
- The risk due to stochastic effects is extremely small. As a result, UNSCEAR states that radiation is a weak carcinogen, estimating that "about 4% of deaths due to cancer can be attributed to ionizing radiation, most of which comes from natural sources that are not susceptible to control by man".* The impact of radiation from peaceful nuclear activities is, as indicated, even substantially lower. ❒

*UNSCEAR recalls that even for the heavily exposed populations that survived the atomic bombing of Hiroshima and Nagasaki in 1945, "of 3350 cancer deaths, only about 350 could be attributed to radiation exposure from the atomic bombing".

Forsmark nuclear power plant in Sweden.
(Credit: G. Hansson)

Director General addresses United Nations General Assembly

In an address to the United Nations General Assembly 1 November 1993, IAEA Director General Hans Blix stated that the Agency is further reinforcing its verification activities to meet new challenges in areas of global security and nuclear non-proliferation.

"It is of crucial importance that States' renunciation of nuclear weapons is reliable," he said. "In a world of nuclear disarmament and non-proliferation, there is a need to feel confidence that non-nuclear weapon States are not violating their non-proliferation commitments and that States legally committed to dismantling nuclear weapons do not secretly produce new weapons." He emphasized that the "key to confidence-building is full nuclear transparency" and that the IAEA's safeguards and verification system is being strengthened, particularly with respect to detecting any undeclared nuclear material and installations in States having comprehensive safeguards agreements with the Agency.

Dr. Blix specifically addressed verification activities in the Democratic People's Republic of Korea (DPRK), Iraq, and South Africa. He further noted a number of areas in which safeguards and verification activities will expand or where expansion is possible in light of regional and global developments. Additionally, he reviewed activities of the IAEA in fields of nuclear power and safety, radioactive waste management, and the transfer of nuclear techniques for industrial, health, and environmental applications.

Concerning the DPRK, which has concluded a comprehensive safeguards agreement with the IAEA, Dr. Blix stated that the possible diversion of nuclear material "cannot be excluded". He noted that the DPRK is seeking to restrict the Agency's verification activities and that the area of non-compliance with the safeguards agreement has been widening. "As a result," he said, "a number of verification measures of the DPRK's declared nuclear activities have become overdue, and continuity of some safeguards-relevant data has been damaged. The longer the Agency is precluded from conducting inspection, the more safeguards-relevant data deteriorate, and the less assurance safeguards can provide that even the declared facilities are used exclusively for peaceful purposes." He reaffirmed the Agency's readiness to perform inspection of all declared material and installations, and to consult with the DPRK on all outstanding issues, including the question of inspection of undeclared sites and additional information. He emphasized, however, that the inspection activities are an integral whole, and that they are not a set of activities from which an inspection State can pick and choose.

In Iraq, where the IAEA is conducting nuclear inspections under the mandate of the Security Council, Dr. Blix said that the Agency has phased in certain elements of its ongoing long-term monitoring and verification plan, and that it is in the process of verifying recent information provided by Iraq on suppliers. "There are still some gaps in our knowledge about Iraq's nuclear supply and procurement channels and about sources of scientific and technical information," he said. "We hope that, on the basis of documentation very recently made available by Iraq, the last pieces of this picture will soon be clarified in a way which will contribute towards full and effective long-term monitoring. This will be essential to give assurance that Iraq does not

UN General Assembly commends IAEA efforts

In a resolution adopted 1 November 1993, the UN General Assembly commended the efforts of the IAEA and called for international co-operation in carrying out the Agency's work.

The resolution specifically commends the IAEA's efforts to implement the safeguards agreement with the Democratic People's Republic of Korea (DPRK) and urged that country to cooperate immediately in the process.

It further commended the Agency's efforts in implementing Security Council resolutions on the disarmament of Iraq and endorsed efforts to put in place the necessary measures for future ongoing monitoring.

The resolution affirmed the Assembly's confidence in the role of the IAEA in the application of nuclear energy for peaceful purposes. It urges States to strive for harmonious international cooperation in promoting the use of nuclear energy and the application of necessary safety measures, in strengthening technical assistance and cooperation for developing countries, and in ensuring the effectiveness and efficiency of the IAEA's safeguards system.

seek to reacquire proscribed nuclear capability." Based on the results of some 21 inspection missions and related activities, the IAEA has been able to conclude that in all essential aspects Iraq's former clandestine nuclear weapons programme has been mapped, and is either destroyed or neutralized, he said.

Concerning South Africa, Dr. Blix cited results of 22 safeguards missions to the country over the past 2 years under a comprehensive safeguards agreement concluded in September 1991, and of additional verification activities undertaken following the South African government's announcement earlier this year that it had terminated and destroyed its former nuclear weapons programme. He said that the IAEA has found "no indication" casting doubt on the veracity of South Africa's initial declaration of nuclear material and installations, or on its subsequent statement that all the highly enriched uranium from its terminated nuclear weapons programme had been reported in the initial declaration.

Regarding expanding safeguards activities and possible new roles for the IAEA, Dr. Blix cited a number of areas. They include IAEA safeguards activities in Argentina and Brazil, where he said "a good example" has been set of mutual openness and confidence-building in nuclear activities. Comprehensive IAEA safeguards will be implemented in these two countries, he said, under a quadripartite safeguards agreement signed in December 1991 and now approved by the Argentine Parliament and the Lower House of the Brazilian Congress. He further noted positive developments in Africa towards the establishment of a nuclear-weapon-free-zone, and in the Middle East, where all the Parties to the peace process support the concept of a zone free of nuclear and other weapons of mass destruction. Dr. Blix noted that he has been consulting with States in the Middle East to facilitate the early application of full-scope Agency safeguards to all nuclear activities in that region, and that the IAEA's Member States recently have asked him to provide whatever assistance may be requested by the Parties in support of the multilateral peace process. In States of the former Soviet Union, he noted that the IAEA also has undertaken much preparatory work for the introduction of comprehensive safeguards in anticipation of their adherence to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT).

The Director General also pointed to developments in areas of nuclear disarmament and arms control that may lead to new roles for the IAEA. These developments include emerging interest in international arrangements for ensuring the safety and security of plutonium and highly enriched uranium, where some preliminary work already has been initiated at the IAEA; a verified cut-off of production of fissionable material for military purposes; and a ban on any kind of nuclear explosive testing.

40TH ANNIVERSARY OF "ATOMS FOR PEACE". Forty years ago — on 8 December 1953 — US President Dwight D. Eisenhower addressed the UN General Assembly and proposed the creation of an international atomic energy agency to help ensure the development of "atoms for peace". *(Credit: United Nations)*

Highlights of the 1993 IAEA General Conference

High-level governmental representatives, including 12 ministers from 96 countries, adopted resolutions in key areas of nuclear development at the 37th regular session of the IAEA General Conference. By acclamation, the Conference approved the reappointment of Dr. Hans Blix to a fourth consecutive 4-year term of office as the IAEA's Director General.

The week-long session concluded 1 October 1993 in Vienna. Elected as President of the General Conference was Mr. Saleh Abdulrahman Al-Athel of Saudi Arabia. The adopted resolutions included those relating to:

Safeguards in the Democratic People's Republic of Korea (DPRK). The Conference adopted a resolution on the implementation of the agreement between the Agency and the DPRK for the application of safeguards in connection with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). It urges the DPRK to "co-operate immediately" in allowing the IAEA to fully implement the comprehensive safeguards agreement for verifying the State's declared nuclear activities. The resolution strongly endorses actions that have been taken so far by the IAEA to implement the safeguards agreement, which the DPRK concluded with the Agency pursuant to the NPT and which has been in force since April 1992. It further expresses the General Conference's "grave concern that the DPRK has failed to discharge its safeguards obligations and has recently widened the area of non-compliance by not accepting scheduled Agency ad hoc and routine inspections as required by its safeguards agreement". The resolution was adopted by vote, with 72 Member States in favour, two against, and eleven abstentions.

Strengthening the IAEA's safeguards system. The resolution expresses the conviction that Agency safeguards can increase confidence among States and help strengthen their collective security. It requests the IAEA Director General "to continue and intensify his efforts towards improving the effectiveness and cost-efficiency" of the safeguards system. It particularly requests the Director General to "pursue the effort of re-examination of safeguards implementation" so that a more effective and cost-efficient system may be achieved covering all nuclear material in all peaceful nuclear activities within the territory of a State having a comprehensive safeguards agreement.

Nuclear safety. The resolution urges the Group of Experts convened under IAEA auspices to continue its work on a nuclear safety convention, and stresses the desirability of holding a diplomatic conference in 1994 on the basis of a comprehensive draft text worked out by the Group.

Ambassador Walker. *(Credit: J. Perez, IAEA)*

IAEA Board of Governors 1993-94

The IAEA's newly constituted Board of Governors for 1993-94 has elected the Governor of Australia, Mr. Ronald Alfred Walker as Chairman, succeeding Mr. Ramtame Lamamra from Algeria.

Mr. Walker has been Australia's Ambassador to Austria and Permanent Representative to the United Nations organizations in Vienna since 1988, following senior diplomatic positions in Asia and Europe. He was Australia's Ambassador to Denmark from 1980-83 and also served as Leader of Australia's delegation to the Committee on Disarmament from 1980-81. He was later Assistant Secretary of the Disarmament and Arms Control Branch and, from 1984-88 served as Special Disarmament Adviser and First Assistant Secretary of the Disarmament, Defense and Nuclear Division.

Elected Vice Chairmen were Mr. József Vigassy, the Governor from Hungary, and Mr. Argus Tarmidzi, the Governor from Indonesia.

The 35 Member States on the Board for 1993-94 are Argentina, Australia, Brazil, Canada, Chile, China, Colombia, Cuba, Egypt, Ethiopia, Finland, France, Germany, Hungary, India, Indonesia, Ireland, Italy, Japan, Lebanon, Libyan Arab Jamahiriya, Malaysia, Nigeria, Paraguay, Philippines, Poland, Russian Federation, Saudi Arabia, Sweden, Switzerland, Syrian Arab Republic, Tunisia, Ukraine, United Kingdom, and United States.

Fellowships in nuclear science and technology: Applying the knowledge

Nearly 1200 scientists, engineers, and specialists receive training each year under IAEA-supported fellowships and scientific visits

by John P. Colton

Over the past three decades, the combined, co-ordinated efforts of people in dozens of countries have been responsible for the selection, placement, and training of more than 16 000 engineers, scientists, specialists, and technicians under the IAEA's programme for fellowships and scientific visitors.

The numbers alone tell only part of the story. Many of these "alumni" of this co-operative training programme today are managing institutions and agencies in their home countries where nuclear technologies are being used for peaceful applications. Others are in senior positions at international organizations, including the IAEA.

Since its initiation in 1958, the programme has passed through various evolutionary stages. Training today is strongly oriented towards practical learning related to the use of nuclear techniques rather than theoretical studies. Individual training for fellows, for example, is designed to provide an in-depth understanding of a particular technology, whereas the training of scientific visitors reflects the growing interest in the application and commercialization of applied nuclear technologies. The programme covers such subjects as physical and chemical sciences, the use of radioisotopes in marine biology and industrial applications, nuclear power and safety, radiation protection, agriculture, and health.

Over the past quarter century, donor countries have financially supported — at a total cost of more than US $120 million — the training of fellows and scientific visitors from more than 95 IAEA Member States.

Mr Colton is Head of the IAEA Fellowships and Training Section in the Department of Technical Co-operation. A more comprehensive report on the programme is featured in the 1994 edition of the *IAEA Yearbook*, available for purchase from the IAEA Division of Publications.

This article reviews the programme, from the standpoint of its historical development, co-operative framework among nominating and host countries, the selection criteria, and plans and expectations for the coming years.

Historical development and trends

Throughout the years, the experiences gained by IAEA trainees have fostered the transfer of scientific and theoretical aspects of nuclear technologies. As importantly, they have given managerial and leadership support to their home institutes and organizations. Interviews with hundreds of fellows and scientific visitors confirm the fact that one of the most important benefits of the training is the practical aspect — to see how something is accomplished, and to apply that knowledge for the benefit of others.

One does not have to look far to find managers who once received IAEA support during their time of education and training. A large number of trainees have become senior leaders in the national and international communities. Within the IAEA's own technical co-operation department, for example, a significant percentage of Directors and Section Heads are former IAEA fellows. Other IAEA technical departments also have senior officers who received technical training with the IAEA's assistance. Additionally, many heads of national atomic energy authorities and institutes have benefitted from the Agency's training programme during their careers. Also interesting to note is that several members of the IAEA Board of Governors and their primary staff members are among the distinguished alumni of the fellowship and scientific visitors programme.

The programme has gone through various stages of development. During the late 1950s and early 1960s, countries principally were interested in having individual scientists receive

IAEA budget and extrabudgetary resources for 1993. The adopted budget resolution approves expenditures for 1994 of US $200 million. This represents zero growth in real terms. The Conference further approved the target amount of US $58.5 million for the IAEA Technical Assistance and Co-operation Fund for 1994.

Denuclearization of Africa. The Conference adopted a resolution by acclamation on an African nuclear-weapon-free-zone (NWFZ). In recognizing that the full disclosure of South Africa's nuclear facilities and materials is a contributing factor to the region's peace and security and to current efforts for establishing a NWFZ, the resolution specifically requests South Africa to continue "its stated policy of full transparency". It further commends the African States for their efforts directed towards establishing an African NWFZ, and asks the IAEA's Director General to continue to assist them in these efforts.

Nuclear inspections in Iraq. In deciding to remain seized of this issue, the Conference adopted a resolution on the implementation of United Nations Security Council Resolutions 687, 707, and 715 relating to Iraq. The resolution demands that Iraq "immediately and fully comply" with all of its obligations under relevant Security Council resolutions, including the requirement that Iraq submit a "full, final and complete declaration of its nuclear programme" which includes all information called for by the Security Council, particularly on outstanding questions about the foreign suppliers of specific items used in Iraq's nuclear programme and the sources which provided Iraq with technical advice, and including acceptance of the plan for future ongoing monitoring. The resolution requests the Agency's Director General to continue putting into place the necessary measures for implementing the future monitoring plan in Iraq, and to report the views of the General Conference to the Secretary-General of the United Nations. The resolution was adopted by vote, with 73 Member States in favour, nil against, and four abstentions.

Safeguards in the Middle East. The Conference adopted by acclamation a resolution on the application of IAEA safeguards in the Middle East. It specifically requests the IAEA's Director General to continue consultations with the States of the Middle East to facilitate the early application of full-scope Agency safeguards to all nuclear activities in the region as relevant to the preparation of model agreements, as a necessary step towards the establishment of a NWFZ. It calls upon all States in the region to take measures, including confidence-building and verification measures, aimed at establishing a NWFZ in the Middle East.

Conference scientific programme

In conjunction with the General Conference, representatives from Member States attended a scientific programme on three topics: nuclear technologies for industrial development and the environment, health consequences of radiation exposure, and options for the back-end of the nuclear fuel cycle.

The programme on nuclear technologies, chaired by Mr. M. Mondino of Argentina, provided an opportunity for non-specialists to learn about the economic and ecological benefits of non-power applications of nuclear technology for environmentally sustainable industrial development. It featured presentations on industrial projects in the Asia and Pacific region supported by the IAEA and United Nations Development Programme; radiation technologies for environmental protection; industrial applications of radioisotopes and radiation; and nucleonic control systems. The programme on health consequences of radiation exposure was designed to provide insight into the ways in which the risks of radiation exposure are determined, and to put them into perspective. Topical issues that were discussed included the limitations of radioepidemiological assessment; natural radiation exposure and associated health risks; and radiation accidents and their health consequences. The programme on the back-end of the nuclear fuel cycle discussed and evaluated issues from short- and long-term perspectives regarding options for an open or closed fuel cycle. The various strategies being followed in France, Japan, India, Russian Federation, United States, and Switzerland were presented.

Additionally during the General Conference, a traditional meeting of senior national and international officials in areas of nuclear safety and radiation protection was convened, as were meetings for representatives from Member States participating in regional technical co-operation arrangements for Africa, Latin America, and Asia and the Pacific.

Looking Ahead: IAEA Symposium on International Safeguards

In co-operation with four other organizations, the IAEA is organizing an International Symposium on Safeguards in Vienna, Austria, from 14-18 March 1994. The meeting is being planned in co-operation with the American Nuclear Society, European Safeguards Research and Development Association, Institute of Nuclear Materials Management, and Nuclear Society International, based in Moscow.

A range of topics are scheduled for discussion. They include experience in special verification situations; strengthened and more cost-effective safeguards; safeguards for plutonium, uranium enrichment, fuel fabrication, and spent fuel storage facilities; containment and surveillance technology; safeguards approaches and evaluation; and regional and national systems for accounting and control of nuclear material.

Participation in the symposium must be through designation by the government of an IAEA Member State or by an invited organization. Forms may be obtained from IAEA Conference Services, or from competent official national authorities (typically the Ministry of Foreign Affairs or national atomic energy authority). Completed forms should be submitted through appropriate government channels for transmission to the IAEA.

Nuclear techniques in animal husbandry

The Food and Agriculture Organization of the United Nations (FAO) and the IAEA have jointly established a Central Laboratory for advancing the use of enzyme-linked immunosorbent assay (ELISA) and molecular techniques in the diagnosis of animal diseases. The Central Laboratory — to operate within the existing Animal Production Unit of the IAEA's Laboratories at Seibersdorf, Austria — will develop and distribute diagnostic kits in support of FAO and IAEA programmes assisting veterinary services in developing countries. It will work in close co-operation with the World Health Organization and the International Office of Epizootics to develop and apply internationally accepted standards for conducting these assays and for assuring the validity of the results.

Animal diseases due to bacteria, viruses, and parasites contribute to malnutrition and reduce agricultural production and income generation in developing countries; some also act as barriers to international trade in livestock and livestock products. New diagnostic techniques, such as ELISA and DNA probe assays, have proven to be more accurate and reliable in erradicating or controlling animal diseases, but they are not yet widely available in developing countries. By acting as the focal point for the development of international standards and the transfer of diagnostic methods based on biotechnology, the FAO/IAEA Central Laboratory is expected to play a key role in assisting developing countries to reduce the impact of animal diseases and the cost of their control.

INES receiving high marks

The International Nuclear Event Scale (INES) is becoming increasingly effective in serving its primary purpose of communicating to the public the significance of nuclear events and putting them into perspective. That was one of the conclusions reached by national INES officers meeting at the IAEA in November 1993. In reviewing the Scale's operation, the officers agreed that INES implementation is progressing very well, with 53 countries applying it. They noted that the Scale now has been fully adopted for use in classifying events at nuclear power reactors since early 1992, and that efforts are being made to improve or further develop detailed guidance on its full use for installations other than power reactors.

INES was designed by an international group of experts convened jointly by the IAEA and Nuclear Energy Agency of the Organization for Economic Co-operation and Development. Events are classified at seven levels, either as incidents (levels 1-3) or accidents (levels 4-7), depending on their severity. INES was developed as a tool to promptly and consistently communicate the safety significance of reported events at nuclear installations, in the interests of fostering common understanding among the public, media, and nuclear community.

United States: Non-proliferation policy

In an address to the UN General Assembly on 27 September, United States President Clinton outlined a framework for US efforts to prevent the proliferation of weapons of mass destruction and the missiles that deliver them. Concerning nuclear non-proliferation, key elements of the US policy include a comprehensive approach to the growing accumulation of fissile material from dismantled nuclear weapons and within civil nuclear programmes. Under the announced approach, the US will propose a multilateral convention prohibiting the production of highly enriched uranium or plutonium for nuclear explosives purposes or outside of international safeguards, and it will submit US fissile material no longer needed for its deterrent to inspection by the IAEA. The US policy further underscores the country's commitment to secure the indefinite extension of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) in 1995, to ensure that the IAEA has the resources needed to implement its vital safeguards responsibilities, and to work to strengthen the IAEA's ability to detect clandestine nuclear activities.

Republic of Korea: Advanced reactors

Future energy needs, including possible roles for nuclear power, and the status of advanced nuclear reactor systems were reviewed at an international symposium organized jointly by the IAEA and the Korea Electric Power Corporation (KEPCO) in Seoul from 18-22 October 1993. About 400 experts from 29 countries and five international organizations attended the symposium, which featured an address by IAEA Director General Hans Blix.

Various presentations on the design and safety objectives of advanced reactor systems highlighted their enhanced safety, greater simplicity and, as a basic requirement, their economic competitiveness with the current generation of nuclear power plants. Participants also had extensive discussion on the impediments to and strategies for the deployment of advanced nuclear power systems. They identified some common elements, such as insufficient public confidence, the need to demonstrate the existence of solutions for waste disposal, the need for a stable and efficient licensing process, and the necessity for regaining investor interest. It was underlined that greater efforts should be made to enhance public awareness of the economic and environmental advantages of nuclear power.

Participants suggested that the next generation of water-cooled reactors currently under design and licensing would be the main contributor to any revival of nuclear power over the short and medium term. They additionally identified a potential market for small and medium sized reactors and noted that breeder reactors may be needed in the long term and that more innovative reactors may become commercially viable and attractive. A number of specific suggestions were also made for future activities, such as the possible harmonization of design and safety objectives to improve deployment prospects of advanced nuclear power systems, and a possible role for international organizations in establishing a demonstration project.

Canada: Nuclear economics

Canada's nuclear industry is making significant contributions to the country's economy, based on the results of a report sponsored by Atomic Energy of Canada Limited (AECL). Since commercial electricity was first generated in Canada by nuclear power in 1962, the total contribution to gross domestic product (GDP) by the nuclear industry has been at least $23 billion, the report found. Over the past 40 years, Canadians have invested $4.7 billion in the nuclear industry.

In 1992, $3.7 billion worth of electricity was generated by Canadian nuclear reactors, providing 15% of the country's electric supply. Additionally, the nuclear industry directly employs 30 000 Canadians, including 3200 engineers and scientists, in more than 150 companies. More information about the report, *The Economic Effects of the Canadian Nuclear Industry*, may be obtained from AECL, Chalk River, Ontario, Canada KOJ 1JO.

China and Republic of Korea: Public information seminars

From late October to early November 1993, the Republic of Korea and China separately hosted IAEA public information seminars on nuclear energy for invited journalists, educators, and government officials.

In Seoul, from 26-28 October, the IAEA and the Republic of Korea's Ministry of Science and Technology (MOST) organized a public information seminar on nuclear energy in co-operation with the Organization for Korean Atomic Energy Awareness. Topics on the agenda included nuclear energy and mass media, nuclear public information and education activities in selected countries, and energy and the environment.

In Shanghai, from 1-3 November, the IAEA in co-operation with the China National Nuclear Corporation organized a regional seminar on nuclear energy for journalists. Presentations were made on nuclear power development policy in Asia, the risks and benefits of modern nuclear power plants, public information for nuclear energy, and the nature and utilization of radiation. The seminar included a technical visit to the Qinshan nuclear power plant.

Armenia, Czech Republic, Slovak Republic: IAEA Members

Three States — Armenia, the Czech Republic, and the Slovak Republic — have deposited the required legal instruments for becoming Member States of the IAEA. The memberships were approved by the IAEA General Conference in September 1993; the legal instruments were deposited on 27 September. There are now 117 IAEA Member States.

The General Conference also approved the memberships of three other States — the Marshall Islands, Kazakhstan, and the Former Yugoslav Republic of Macedonia.

United Kingdom: Radiation report

The National Radiological Protection Board (NRPB) in the United Kingdom has issued a report assessing the collective doses arising from past and proposed future releases from the British Nuclear Fuels site at Sellafield. The report considered the collective doses to three population groups — those in the United Kingdom, Europe, and the world at large. In each case, the Sellafield collective dose, which is delivered at very low values over a protracted period, was found to be very small compared with the collective dose from natural or medical sources of radiation.

The report was prepared at the request of the Committee on the Medical Aspects of Radiation in the Environment. More information may be obtained from the NRPB, Chilton, Didcot, Oxon OX11 ORQ, United Kingdom.

BRIEFLY NOTED........................

NUCLEAR LAW. Three officials of the IAEA have edited a new book, *The International Law of Nuclear Energy*, the first comprehensive collection of basic documents on the subject. The book was edited by Mohamed M. ElBaradei, IAEA Assistant Director General and Head of the Division of External Relations, and Edwin I. Nwogugu and John M. Rames, senior staff members of the IAEA's Legal Division. It covers documentation concerning nuclear non-proliferation and safeguards, nuclear safety, radioactive waste management, transport of radioactive material, radiation protection, and physical protection of nuclear material, among other areas. More information may be obtained from the publisher, Martinus Nijhoff Publishers, P.O. Box 163, 3300 AD Dordrecht, Netherlands.

PESTICIDES AND THE ENVIRONMENT. The IAEA's Marine Environment Laboratory in Monaco (IAEA-MEL) is organizing a co-ordinated research programme (CRP) on the distribution, fate and effects of pesticides on biota in the tropical marine environment. The programme is being organized in collaboration with the Joint Division of the IAEA and Food and Agriculture Organization of the United Nations. It aims to promote development of national capacities in developing countries to control and minimize the undesirable effects of pesticide residues in the tropical marine environment and on the human population consuming seafoods from these regions. Special emphasis will be given to the development and application of nuclear-related techniques. Additional information on the technical aspects of the CRP may be obtained from Mr. F.P. Carvalho, IAEA-MEL, P.O. Box 800, MC 98 012 Monaco Cedex, Principality of Monaco.

RADWASTE MAGAZINE. The American Nuclear Society has announced the upcoming publication of *Radwaste Magazine*, a quarterly periodical focusing on issues and approaches in the fields of radioactive waste management and environmental restoration. Although mainly intended to cover developments in the United States, the magazine plans to feature articles on programmes and practices in other countries on an occasional basis. More information may be obtained from the ANS, 555 N. Kensington Ave., La Grange Park, Illinois, USA 60525

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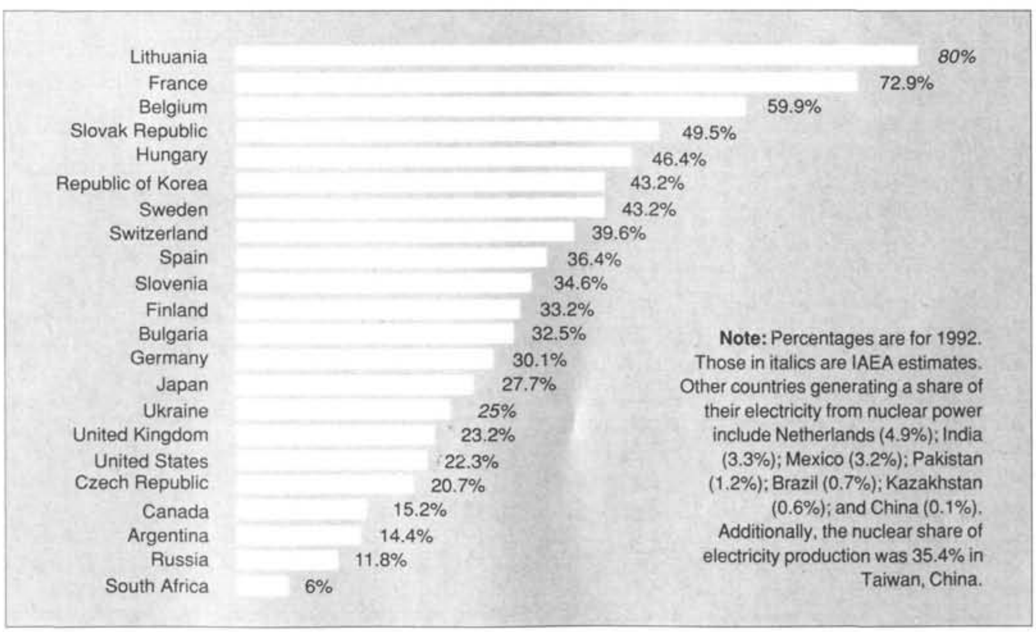
Nuclear power status around the world

	In operation		Under construction	
	No. of units	Total net MWe	No. of units	Total net MWe
Argentina	2	935	1	692
Belgium	7	5 484		
Brazil	1	626	1	1245
Bulgaria	6	3 538		
Canada	21	14 874	1	881
China	1	288	2	1 812
Cuba			2	816
Czech Republic	4	1 632	2	1 784
Finland	4	2 310		
France	56	57 688	5	7 125
Germany	21	22 559		
Hungary	4	1 729		
India	9	1 593	5	1 010
Iran			2	2 392
Japan	44	34 238	9	8 129
Kazakhstan	1	135		
Korea, Rep. of	9	7 220	3	2 550
Lithuania	2	2 760	1	1 380
Mexico	1	654	1	654
Netherlands	2	504		
Pakistan	1	125		
Romania			5	3 155
Russian Federation	28	18 893	18	14 175
South Africa	2	1 842		
Slovak Republic	4	1 632	4	1 552
Slovenia	1	632		
Spain	9	7 101		
Sweden	12	10 002		
Switzerland	5	2 952		
United Kingdom	37	12 066	1	1 188
Ukraine	15	13 020	6	5 700
USA	109	98 729	3	3 480
World total*	424	330 651	72	59 720

* The total includes Taiwan, China where six reactors totalling 4890 MWe are in operation. In 1992 they accounted for 35.4% of the total electricity generated there.

Notes: The data reflect the status at the end of 1992 as reported to the IAEA. For the USA, the table does not reflect the shutdown of one plant reported in February 1993.

Nuclear share of electricity generation in selected countries



Note: Percentages are for 1992. Those in italics are IAEA estimates. Other countries generating a share of their electricity from nuclear power include Netherlands (4.9%); India (3.3%); Mexico (3.2%); Pakistan (1.2%); Brazil (0.7%); Kazakhstan (0.6%); and China (0.1%). Additionally, the nuclear share of electricity production was 35.4% in Taiwan, China.

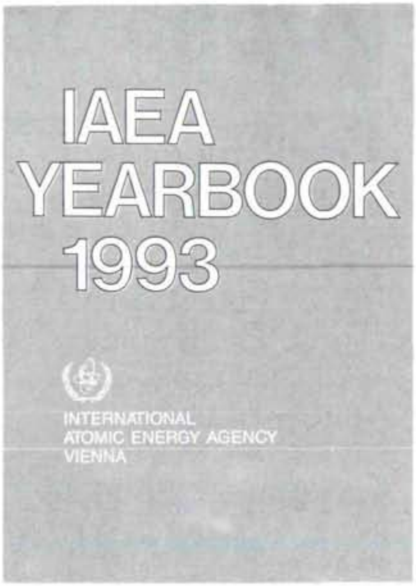
WORLD OVERVIEW

IAEA YEARBOOK 1993

The latest edition of the *IAEA Yearbook* describes developments in nuclear power and advances in nuclear techniques and research, and illustrates the work of the IAEA within a world context. It features detailed summaries of nuclear safety and radiation protection activities in individual countries. Other sections provide data on the nuclear fuel cycle, from uranium resources to the management of radioactive waste, and the operation of nuclear power plants. Coverage includes the present and future costs of nuclear power plant projects; advanced reactor designs not only for electricity generation but also for cogeneration of steam and heat for industrial purposes; supply and demand in various parts of the fuel cycle; and advances in fuel technology. Comprehensive coverage further is provided about the IAEA's safeguards system and its programme for technical co-operation and assistance in various nuclear fields.
(Note: Some sections are sold separately.)
Price: 500 Austrian Schillings
ISBN 92-0-102493-2 (STI/PUB/935)

Nuclear Power, Nuclear Fuel Cycle and Waste Management: Status and Trends 1993
Part C of the IAEA Yearbook 1993

This publication covers: nuclear power, including individual summaries of programme developments in various countries; fuel cycle related themes, including uranium resources, conversion enrichment, reactor fuel technology and spent fuel management; and radiation waste management, including treatment and conditioning, disposal, decontamination and decommissioning. The 1992 situation in these areas is described in detail, as are the projected trends over the next two decades.
Price: 200 Austrian Schillings
ISBN 92-0-102593-9 (STI/PUB/936)



Nuclear Safety Review 1993
Part D of the IAEA Yearbook 1993

This review summarizes developments in nuclear safety and radiation protection, including the growing number of projects being organized jointly by regional and international organizations. A description is given of the IAEA programmes related to the safety of reactors of Soviet design and of the recent initiative, in conjunction with the United Nations Development Programme, on strengthening infrastructures for radiation and nuclear safety in the newly independent States. The review also presents an update on the causes of the Chernobyl accident and describes progress in the application of the International Nuclear Event Scale and probabilistic safety analysis techniques. Other topics covered include the new international Basic Safety Standards for radiation protection and the safe transport of radioactive material.
Price: 200 Austrian Schillings
ISBN 92-0-102693-5 (STI/PUB/937)

PLASMA PHYSICS AND NUCLEAR FUSION

Plasma Physics and Controlled Nuclear Fusion Research 1992
Vols. 1, 2, 3, and, 4

This publication includes the proceedings of the Fourteenth International Conference in Plasma Physics and Controlled Nuclear Fusion Research held in Wuerzburg, 30 September - 7 October 1992. The Conference was characterized by reports of recent results from all of the major fusion facilities around the world, including the milestone experiment at JET in which tritium was introduced for the first time into a tokamak fuel mixture. The proceedings include all the technical papers, the pertinent discussions, and five conference summaries.
(STI/PUB/906)
ISBN 92-0-101093-1 Price: 2200 AS
ISBN 92-0-101193-8 Price: 1900 AS
ISBN 92-0-101293-4 Price: 1560 AS
ISBN 92-0-101393-0 Price: 240 AS

NUCLEAR AND RADIATION SAFETY

Strengthening Radiation and Nuclear Safety Infrastructures in Countries of the Former USSR

This book includes the proceedings of a forum organized by the United Nations Development Programme and the IAEA, and held in Vienna, 4-7 May 1993. It represents the first step of a joint project to provide the countries of the former USSR an integrated package of assistance to strengthen the overall national infrastructure for radiation protection as well as for nuclear safety, including the establishment of an adequate legal framework. The main focus is on efforts to improve safety of facilities such as research reactors, uranium mining and milling facilities, and installations containing radiation sources used in medicine, agriculture, and industry.
Price: 300 Austrian Schillings
ISBN 92-0-102793-1 (STI/PUB/939)

FOOD AND AGRICULTURE

Cost-benefit Aspects of Food Irradiation Processing
Proceeding Series

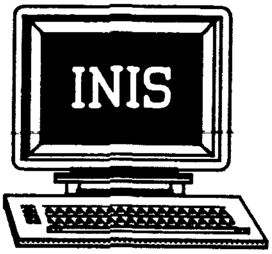
This book presents the proceedings of a Symposium jointly organized with FAO and WHO in March 1993. The purpose of the symposium was to evaluate the costs and benefits of irradiation for treating various food items either alone or in combination with other processes. The evaluation covered application of the technology in terms of reducing food losses as well as the possible economic impact of irradiation in controlling or reducing certain food-borne illnesses and in expanding trade in certain food items. Discussions focused on the economic benefits of irradiation to control a number of food-born diseases and on the potential economic benefits from radiation as a quarantine treatment for fresh fruits and vegetables.
Price: 1400 Austrian Schillings
ISBN 92-0-000393-1 (STI/PUB/905)

Management of Insect Pests: Nuclear and Related Molecular and Genetic Techniques
Proceeding Series

This book contains the proceeding of a symposium jointly organized with FAO, and held in Vienna, 19-23 October 1992. In the past decade significant progress has been made in overcoming many of the difficulties of biologically based methods of pest management. Particularly important are the advances made in the field of molecular technology and biotechnology. Presentations in this symposium focus on advances and trends in insect control and eradication, genetic engineering and molecular biology, insect genetics, operational programmes, sterility and behaviour, biocontrol, and quarantine.
Price: 1900 Austrian Schillings
ISBN 92-0-000293-5 (STI/PUB/909)

ON LINE DATABASES

OF THE INTERNATIONAL ATOMIC ENERGY AGENCY



Database name

International Nuclear Information System (INIS)

Type of database

Bibliographic

Producer

International Atomic Energy Agency in co-operation with 82 IAEA Member States and 16 other international member organizations

IAEA contact

IAEA, INIS Section, P.O. Box 100,
A-1400 Vienna, Austria
Telephone (43) (1) 2360
Telex (1)-12645
Facsimile +43 1 234564
Electronic mail via EARN/BITNET-INTERNET to ID:
NI5@IAEA1.IAEA.OR.AT

Number of records on line from January 1976 to date

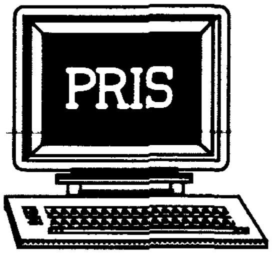
more than 1.5 million

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 the economic and environmental aspects of non-nuclear energy sources. Legal and social aspects associated with nuclear energy also are covered.



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

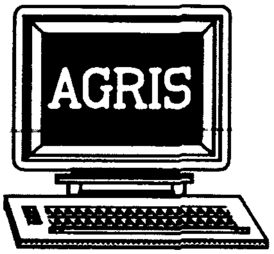
IAEA, Nuclear Power Engineering Section, P.O. Box 100
A-1400 Vienna, Austria
Telephone (43) (1) 2360
Telex (1)-12645
Facsimile +43 1 234564
Electronic mail via EARN/BITNET-INTERNET to ID:
NES@IAEA1.IAEA.OR.AT

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) 2360
Telex (1)-12645
Facsimile +43 1 234564
Electronic mail via EARN/BITNET-INTERNET to ID:
FAS@IAEA1.IAEA.OR.AT

Number of records on line from January 1992 to date

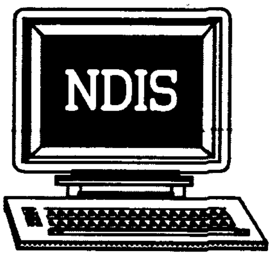
more than 150 000

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) 2360
Telex (1)-12645
Facsimile +43 1 234564
Electronic mail via EARN/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

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

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 obtained from the producer on diskettes, magnetic tape, or hard copy.

POSTS ANNOUNCED BY THE IAEA

UNIT HEAD, OPERATIONAL SAFETY EXPERIENCE FEEDBACK (93-075), Department of Nuclear Energy and Safety. This P-5 post requires a Doctorate in nuclear engineering and experience in analysis of incidents/accidents, and at least 15 years of experience in the field of nuclear safety. *Closing date: 28 February 1994.*

RADIATION SOURCE SPECIALIST (93-072), Department of Nuclear Energy and Safety. This P-4 post requires a Doctorate or equivalent degree in the field of radiation protection or related physical sciences, and at least 10 years of experience in radiation protection, including at least 5 years practical experience in the use and optimization of medical and industrial radiation sources. *Closing date. 28 February 1994.*

ENVIRONMENTAL PROTECTION SPECIALIST (93-073), Department of Nuclear Energy and Safety. This P-4 post requires a university degree in a relevant field of science, and at least 10 years of experience in radiation protection, five of which should have been in radiation protection of the general public and the environment, and knowledge of protection philosophy, dose assessment models, protective actions, and their associated computer realizations. *Closing date · 28 February 1994*

SENIOR RESEARCH REACTOR SAFETY OFFICER (93-074), Department of Nuclear Energy and Safety. This P-5 post requires a Doctorate or equivalent advanced degree in the physical sciences or nuclear engineering, and at least 15 years of experience in the operation of medium or high power and complex research reactors, including the preparation of safety documentation for their licensing and operation. *Closing date: 28 February 1994.*

RADIATION PROTECTION SPECIALISTS, Department of Nuclear Energy and Safety. Two positions: one (93-601) is graded P-4 and requires a Masters degree or equivalent advanced degree in the field of science or engineering and at least 10 years of extensive experience in human resources development and practical knowledge of the IAEA's Basic Safety Standards for radiation protection. The other position (93-602) is graded P-5 and requires a Doctorate or equivalent advanced degree in the field of radiation protection or related sciences and 15 years of experience in assessment and control of radon exposure and in areas of radiation protection for uranium mining and milling. For both posts, the duration of appointments is subject to the availability of extra-budgetary funds. *Closing date: 28 February 1994.*

TRANSPORT SAFETY SPECIALIST (93-603), Department of Nuclear Energy and Safety. This P-4 post requires a university degree in the field of science or engineering, and at least 10 years of experience related to the management of the transportation of radioactive materials, and practical knowledge of the development and application of the IAEA's transport regulations and supporting documentation. The duration of the appointment is subject to the availability of extra-budgetary funds. *Closing date: 28 February 1994.*

CO-ORDINATOR, EMERGENCY ASSISTANCE SERVICES (93-604), Department of Nuclear Energy and Safety. This P-5 post requires an advanced degree in radiation protection or related physical sciences, and at least 15 years of experience in radiation protection and emergency planning and preparedness. The duration of the appointment is subject to the availability of extra-budgetary funds. *Closing date: 28 February 1994.*

SAFETY STANDARDS SPECIALIST (93-605), Department of Nuclear Energy and Safety. This P-5 post requires a Doctorate or equivalent advanced degree in engineering or physical sciences, and at least 15 years of experience in nuclear safety matters, including technical reviews and standards development, part of which has been at a senior technical level. The duration of the appointment is subject to the availability of extra-budgetary funds. *Closing date: 28 February 1994.*

OPERATIONAL SAFETY EXPERIENCE SPECIALIST (93-606), Department of Nuclear Energy and Safety. This P-5 post requires a Doctorate in nuclear engineering or physics, as well as 15 years of experience in nuclear safety, particularly operational safety. The duration of the appointment is subject to the availability of extra-budgetary funds. *Closing date: 28 February 1994.*

SENIOR OPERATIONAL SAFETY OFFICER (93-607), Department of Nuclear Energy and Safety. This P-5 post requires a Doctorate or equivalent advanced degree in engineering or physical sciences, and at least 15 years of experience in the operation of nuclear power plants, with extensive experience in plant operations and technical support at the senior level. The duration of the appointment is subject to the availability of extra-budgetary funds. *Closing date: 28 February 1994*

SAFETY ASSESSMENT SPECIALISTS, Department of Nuclear Energy and Safety. Two positions: Both posts (93-608 and 93-609) are graded P-5 and require a Doctorate or equivalent advanced degree in engineering or physics, and at least 15 years of experience in nuclear safety. The duration of the appointments will be subject to the availability of extra-budgetary funds. *Closing date: 28 February 1994.*

COMPARATIVE SAFETY ASSESSMENT SPECIALIST (93-610), Department of Nuclear Energy and Safety. This P-5 post requires an advanced degree in engineering or in a relevant field of science, and at least 15 years of experience in the field of risk assessment. The duration of the appointment is subject to the availability of extra-budgetary funds. *Closing date: 28 February 1994.*

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. 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 Services. 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 NESIRS01.IAEA.OR.AT (161.5.64.10), and then log on using the identification *anonymous* and your user password. 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.

IAEA UPCOMING CO-ORDINATED RESEARCH PROGRAMMES

Comparative evaluation of the efficacy and toxicity of orally administered phosporus-32 and intravenously administered strontium-89 in the palliation of painful skeletal metastases
To identify the optimum agent among these two radionuclides for palliative treatment of patients in developing countries where resources for cancer management are very limited.

Collection and evaluation of reference data for thermo-mechanical properties of fusion reactor plasma facing materials
To collect and critically assess thermo-physical and thermo-mechanical properties of plasma facing materials for fusion reactors. The evaluated data will be placed in the ALADDIN materials properties database and disseminated to users, especially fusion reactor designers.

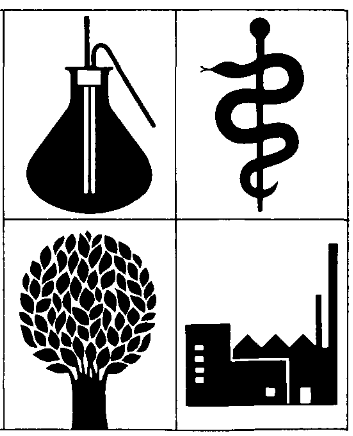
Design and evaluation of heat utilization systems for the high temperature engineering test reactor (HTTR)
To establish design concepts and development needs for selected candidate heat utilization systems which are of international interest, and to evaluate these systems regarding safety and status of technology for potential demonstration at the Japanese high temperature engineering test reactor.

Evaluation of the safety, environmental, and non-proliferation aspects of partitioning and transmutation of actinides and fission products
To promote the exchange of information on the results obtained by different countries in order to clarify the objectives which should be pursued by partitioning and transmutation and to enlarge the scientific basis for examining its potential for enhancing the safety of the nuclear fuel cycle. The results of this programme will also give the opportunity to Member States to define the scope of further research and development work required in this field.

Automation in tsetse fly mass-rearing for use in sterile insect technique programmes
To develop automated techniques which would replace laborious aspects of mass-rearing. This recommendation was based on an economic analysis of tsetse mass-rearing which indicated that labour costs and related expenses exceeded 50% of the total cost of mass-rearing.

Standardized methods to verify absorbed dose of irradiated fresh and dried fruits, and tree nuts in trade
This CRP aims at developing standardized methods to verify the absorbed dose required for insect disinfestation of dried fruits and tree nuts and for quarantine treatment of fresh fruits and vegetables by irradiation, in their respective commercial packages. It will evaluate the efficacy of pilot or semi-commercial scale irradiation of dried fruits and tree nuts as an alternative to fumigation by methyl bromide and as a public health measure to control food-borne diseases (cysticercosis/taeniasis and Vibrio infection) in Latin America and the Caribbean.

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

FEBRUARY 1994

Seminar on Developments in Radioactive Waste Transport, ***Vienna, Austria*** (21-25 February)

MARCH 1994

IAEA Symposium on International Safeguards, ***Vienna, Austria*** (14-18 March)

AUGUST 1994

(Interregional) Seminar on Isotope Techniques in Arid and Semi-Arid Land Hydrology, ***Vienna, Austria*** (15-26 August)

Interregional Seminar on Radiotherapy Dosimetry: Radiation Dose in Radiotherapy from Prescription to Delivery, ***Brazil*** (27-30 August)

SEPTEMBER 1994

Conference on Nuclear Power Option, ***Vienna, Austria*** (5-9 September)

15th International Conference on Plasma Physics and Controlled Nuclear Fusion Research, ***Madrid, Spain*** (26 September-1 October)

2nd IAEA/FAO Seminar for Africa on Animal Trypanosomiasis: Vector and Disease Control Using Nuclear Techniques, ***Uganda*** (Preliminary)

OCTOBER 1994

Seminar on Radioactive Waste Management Practices and Issues in Developing Countries, ***Beijing, China*** (10-14 October)

International Symposium on Spent Fuel Storage — Safety, Engineering and Environmental Aspects, ***Vienna, Austria*** (10-14 October)

FAO/IAEA International Symposium on Nuclear and Related Techniques in Soil/Plant Studies on Sustainable Agriculture and Environmental Preservation, ***Vienna, Austria*** (17-21 October)

NOVEMBER 1994

Revision Conference of the Vienna Convention on Civil Liability for Nuclear Damage, ***Vienna, Austria*** (Preliminary)

International Conference on Radiation, Health and Society: Comprehending Radiation Risks (Preliminary)

OTHER IAEA MEETINGS
(Selected listing)

IAEA General Conference, Thirty-eighth Regular Session, ***Vienna, Austria***, (19-23 September 1994)

IAEA BULLETIN

Published quarterly by the Division of Public Information of the International Atomic Energy Agency, P.O. Box 100, A-1400 Vienna, Austria.
Tel: (43-1) 2360-1270
Facsimile: (43-1) 234564

IAEA MEMBER STATES

1957
Afghanistan
Albania
Argentina
Australia
Austria
Belarus
Brazil
Bulgaria
Canada
Cuba
Denmark
Dominican Republic
Egypt
El Salvador
Ethiopia
France
Germany
Greece
Guatemala
Haiti
Holy See
Hungary
Iceland
India
Indonesia
Israel
Italy
Japan
Korea, Republic of
Monaco
Morocco
Myanmar
Netherlands
New Zealand
Norway
Pakistan
Paraguay
Peru
Poland
Portugal
Romania
Russian Federation
South Africa
Spain
Sri Lanka
Sweden
Switzerland
Thailand
Tunisia
Turkey
Ukraine
United Kingdom of Great Britain and Northern Ireland
United States of America
Venezuela
Viet Nam
Yugoslavia

1958
Belgium
Cambodia
Ecuador
Finland
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
Democratic People's Republic of Korea
Mauritius

1976
Qatar
United Arab Emirates
United Republic of Tanzania

1977
Nicaragua

1983
Namibia

1984
China

1986
Zimbabwe

1991
Latvia
Lithuania
Yemen, Republic of

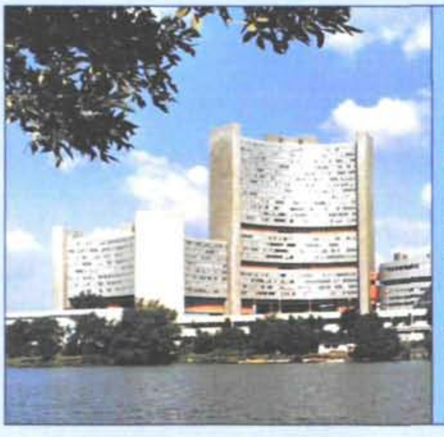
1992
Croatia
Estonia
Slovenia
Uzbekistan

1993
Armenia
Czech Republic
Kazakhstan
Marshall Islands
Slovak Republic
Former Yugoslav Republic of Macedonia

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

ALOKA

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