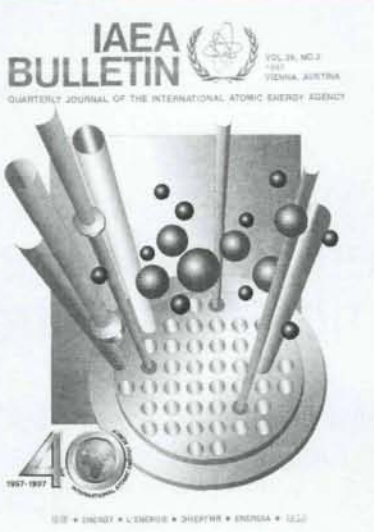


Front cover: Five years ago, the Earth Summit underlined the environmental side of how the world is developing. Global energy demand is a big part of the picture, and it's growing rapidly, especially in regions such as Asia where economic development is strong. But how sustainable is our pattern of energy use in the face of global warming and other environmental threats? And what role should nuclear energy play, which does not emit carbon dioxide or air-polluting gases into the atmosphere as fossil fuels do? At a time when the UN General Assembly is revisiting Earth Summit issues, this edition looks at global energy needs and at ways in which countries are developing nuclear power for electricity generation and other energy-related applications.
Cover design: Hannelore Wilczek, IAEA;
Stefan Brodek, Vienna

Facing page: Children in Ethiopia, where an IAEA-supported project is contributing to studies of old and new water resources. *(Credit: D. Kinley/IAEA)*

CONTENTS

ISSN 0020-6067

Nuclear power development: Global challenges and strategies

Today's global pattern of energy supply is not sustainable, and the future must see a mix of fuels for environmental and other reasons

by Victor M. Mourogov

Five years after the Earth Summit in Rio de Janeiro, a Special Session of the United Nations General Assembly in June 1997 examined progress toward the goals of sustainable development. Sustainable development is linked to protecting the environment and thus unquestionably to the supply and use of energy.

With a combination of industrialization, economic development, and a projected doubling of the world's population in the 21st century, global energy consumption will surely continue to increase. Growth will be driven principally by the demand in developing countries. They now have 75% of the world's inhabitants but consume only 31% of all energy produced worldwide. Conservation and improved efficiency in energy use will restrain but not stop demand. The World Energy Council (WEC) projects growth in energy demand of anywhere between 50% and 300% over the next five decades, depending on environmental and economic factors.

The global energy issue

In view of projected energy demands, today's global pattern of energy supply is not sustainable. There is a solid international consensus that heavy dependence on fossil fuels — which today account for almost 90% of the total energy supply — must be controlled. Their use adversely affects the atmosphere through emissions of greenhouse gases along with other noxious gases and toxic pollutants.

Though it is not problem free, nuclear power is recognized as having a clear advantage in contributing to the goals of sustainable development. For its entire energy chain from fuel production to waste disposal, it has limited emissions of greenhouse gases and other pollutants. Nuclear power currently provides about 6% of global energy and 17% of global electricity supply. Nearly 480 nuclear plants are operating or being built in 32 countries.

Despite the record, there is no international consensus concerning nuclear's future role. The policies of a few countries are absolutely opposed to nuclear power. While some countries are decidedly positive, the majority are passive at best. While nuclear power stagnates in Europe and North America, it continues to expand in Asia. Countries in Eastern Europe and the former Soviet Union, heavily dependent on nuclear power, are experiencing serious difficulties due to a breakdown in the infrastructure necessary to keep the nuclear power plants operational.

The future will see a mix of energy sources. The makeup of this mix cannot be precisely defined — it will depend not only on environmental considerations, but also on technological, policy, and market factors. For many years, fossil fuels are expected to continue to play a major role in energy production. With adequate support the share of new renewable energy supplies should increase. The WEC expects renewables to reach a global energy share of between 5% and 8% in the next 25 years. Hydroelectric's share will likely remain around the current 6%.

The potential of nuclear power

The challenge for the nuclear community is to assure that nuclear power remains a viable option in meeting the energy requirements of

Mr. Mourogov is the IAEA Deputy Director General heading the Department of Nuclear Energy.

the next century. It could be a major provider of electricity for baseload as well as for urban transport in megacities. It can play a role in non-electric applications in district heating, process industries, maritime transport, water desalination, hydrogen production, and for applications in remote areas. It can contribute substantially to the security of energy supply and it has the potential to be an almost inexhaustible long-term energy resource through the use of breeder reactors.

However, the current lack of public support could unquestionably constrain the introduction of new plants. It will be necessary to openly discuss the concerns that have limited nuclear power's acceptance. But discussions of health and environmental impacts along with severe accidents and waste disposal must not be done in isolation as is too frequently the case. As no energy source is risk free, comparative impacts of the various energy systems must be extensively reviewed. Studies of nuclear, fossil, and renewable energy chains show that there are significant issues and impacts inherent in all options.

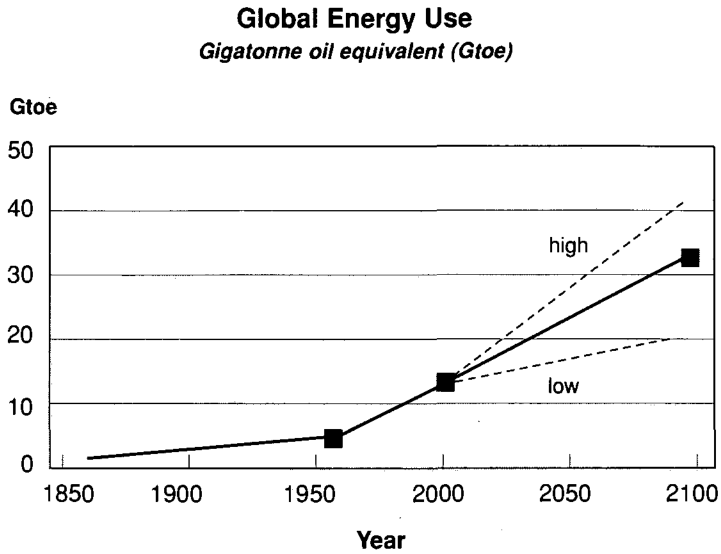
Authoritative comparative assessments illustrate the potential of nuclear power to mitigate energy-related health and environmental damage — it can be shown to be one of the most environmentally acceptable means of generating electricity. If external factors, such as the societal costs of climate change, environmental damage, and health effects were included in all analyses, a clear nuclear advantage would arise over fossil fuels — and the economic competitiveness of nuclear power in a radically changing financial environment would escalate.

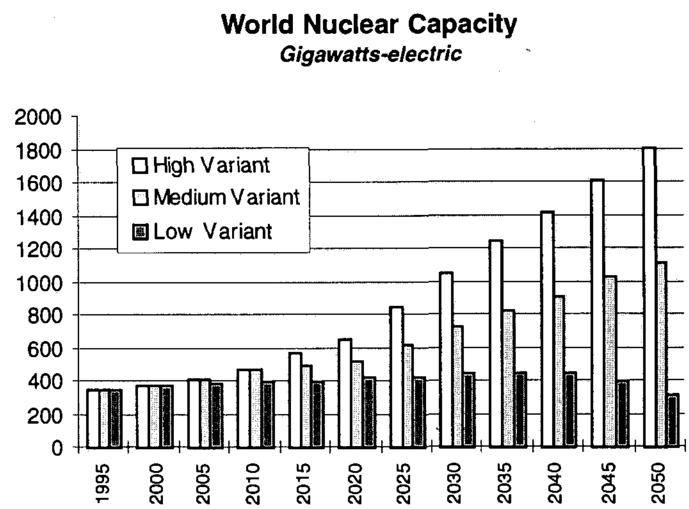
This article highlights key factors that will determine today and tomorrow's optimal energy strategies. It addresses methods to utilize the high potential energy content of uranium. Plutonium use as fuel in nuclear reactors is discussed as is the future potential of a thorium fuel cycle. Various strategies to increase the economic viability of nuclear power are brought out. Technological means to further minimize environmental impacts and to enhance safety are covered as they are a major factor in public acceptance. Also covered are advances anticipated by mid-century in nuclear reactor and fuel cycle technologies.

Fuel cycle and reactor strategies: A look at the key factors

If a significant contribution from nuclear power is to take place by the middle of the next century, a large amount of new generating capacity would be required, averaging as high as 20 new units annually. There are a number of issues relevant to the fuel cycle and the type of reactor desired that must be dealt with now in order to provide the best conditions for an increased nuclear role.

The IAEA's recent Symposium on Nuclear Fuel Cycle and Reactor Strategies: Adjusting to New Realities (held in Vienna, Austria, 2-6 June 1997) addressed a broad range of topics. They included those brought about by the slowdown in nuclear power growth and the large amounts of plutonium expected to be recovered from dismantled nuclear warheads. One Key Issue Paper





specifically focused on future fuel cycle and reactor strategies.

In an increasingly competitive and international global energy market, a number of key factors will affect not only the energy choice, but also the extent and manner in which different energy sources are used. These include:

- optimal use of available resources;
- reduction of overall costs;
- minimizing environmental impacts;
- convincing demonstration of safety; and
- meeting national and global policy needs.

For nuclear energy, these five factors will determine the future fuel cycle and reactor strategies. As the objective is to optimize these factors, they will be discussed sequentially under corresponding headings; maximizing resource utilization, maximizing economic benefits, maximizing environmental benefits, maximizing reactor safety, and satisfying key policy needs.

Although obtaining public acceptance has not been included as a key factor, it is in reality a vital one for nuclear energy. It will be necessary to communicate the real benefits of nuclear power to the public and policy makers in an open and credible manner. The growing public reluctance, particularly in developed countries, to accept new large industrial facilities impacts policies in the entire energy sector and affects the implementation of all power plant projects.

Maximizing resource utilization. Known and likely resources of uranium should assure a sufficient nuclear fuel supply in the short and medium term even with reactors operating primarily on once-through cycles with disposal of spent fuel. However, as uranium demand increases and reserves are decreased to meet the requirements of increased nuclear capacity, there will be economic pressure for the optimal use of uranium in a manner that utilizes its total potential energy content per unit quantity of ore. A variety of means are available to accomplish this during the enrichment process and at the operational stage. Over the longer term, recycling of generated fissionable material in thermal reactors and introduction of fast breeder reactors will be necessary. Thorium could also be a valuable energy resource in the longer term.

Uranium fuel cycle. Isotopic separation technology enables lowering the uranium-235 content in the enrichment process waste tailings. This results in extraction of more of the original 0.7% fraction of this fissionable isotope existing in the natural uranium ore that consists primarily of non-fissionable uranium-238. At the operational stage, higher fuel burn-up cycles will utilize more of the uranium-235 contained in the enriched uranium fuel elements — concurrently reducing the amount of spent fuel relative to the energy produced.

However, reprocessing of spent fuel instead of disposal would allow the recycling of generated plutonium through mixed oxide fuel in thermal reactors as well as in fast breeder reactors and also make available uranium with its fissionable isotopes that are contained in spent fuel. Reprocessing would significantly increase the energy potential of today's uranium resources — theoretically by a factor of around 70 — and also substantially reduce the quantity of troublesome long-lived radioactive elements in the remaining waste. By far, recycling provides the best use of available uranium resources. The current policy of interim spent fuel storage before ultimate disposal preserves the potential for future reprocessing to extract fissionable material, particularly plutonium.

Thorium fuel cycle. Although uranium is likely to remain the main natural resource for nuclear power systems, in the longer term the use of fertile thorium as a feed material is possible. While uranium contains a fissionable isotope, thorium does not. It must be enriched with either fissionable uranium-235 or plutonium to start the fuel cycle. The uranium-233 that is subsequently generated in the reactor from thorium conversion is fissionable. The thorium fuel cycle, with its lower operating fuel temperatures, has advantages in the physical performance of fuel elements and also with respect to the characteristics of the core physics.

The existence of indigenous thorium in a number of countries that have limited uranium deposits would make this an attractive option. Thorium-based fuel cycles have been developed in a number of countries. Among these are the United States, Germany, India, the United Kingdom, Japan, and Canada, with the first three having successfully demonstrated their use in power reactors. The thorium fuel cycle can be used in all types of current systems — light and heavy water as well as high temperature gas and fast reactors — without requiring significant changes in the reactor design or safety concepts.

However, present knowledge of the extent of thorium resources in the world is poor even though extensive deposits with high grade ore have been found. Extraction of thorium from ores is a somewhat difficult process, and its economics are not established. There are also difficulties of separation of the produced uranium-233 from the spent fuel. But the remaining waste is significantly easier to deal with than the waste from the current uranium-based fuel cycle without reprocessing.

Maximizing economic benefits. As fuel costs are relatively low, reduction of overall costs by decreasing development, siting, construction, operation, and initial financing expenses is essential to the overall economic viability of nuclear energy. Removing the uncertainties and variability in licensing requirements, particularly before commissioning, would allow for more predictable investment and financial strategies.

Development costs. The high costs associated with new design development will likely result in less expensive evolutionary improvement of today's reactor systems rather than the more expensive introduction of revolutionary new designs and technologies. Governmental development funding has substantially decreased over the years and as with all mature technologies, the source of funding will shift entirely to the private sector.

Capital costs. The need to reduce high initial capital costs will encourage economies in siting and construction. It will lead to multi-unit sites at existing locations that will also maximize infrastructure investments. There will be more emphasis on plants with standardized systems and components as successfully employed in France. Plant size and unit power levels will be matched to regional needs and the choice of suppliers will be based on long-term economics rather than on short-term advantages.

Operations. In the operational area, reduction in costs will require high availability and load factors brought about by high quality systems, long core fuel cycle periods, short shutdown times and the ability to rapidly return to power. There will be a continued evolution of separate organizations providing various plant and fuel cycle services, particularly on a regional basis.

Licensing. Some of the high capital costs of new facilities and extended construction periods are related to the uncertainties and demands in licensing requirements. Uncertain waste management and decommissioning requirements and costs deter investments. These factors may lead to a rationalization of the licensing process leading to more certainty in regulation and a concurrent decrease in the time from site selection to operation. Waste and decommissioning requirements based on comparative assessments of other industrial practices may lead to a more practical approach to radioactive material without compromising safety.

Financing. Innovative and novel investment strategies will be needed to meet evolving and changing investment goals. The large initial capital investments required for nuclear power projects could be easier to raise in the framework of multinational funding arrangements. Build, operate and transfer arrangements may be used in developing countries that allow for adequate returns on non-domestic investments before shifting ownership. Incremental investment strategies through modular energy systems would also decrease initial financing needs.

Maximizing environmental benefits. Although nuclear energy has distinct advantages over today's fossil burning systems — in terms of fuel consumed, pollutants emitted and waste produced — further reducing environmental concerns can have a major influence on public attitudes.

As the overall health and environmental impact of the nuclear fuel cycle is small, attention will be directed at improved techniques to deal with radioactive waste. This would support global sustainable development goals and at the same time increase competitiveness with other energy sources that will be required to adequately deal with their waste. Reactor systems and fuel cycles can be adjusted to minimize waste production. Design requirements to decrease waste quantities and volume reduction techniques such as ultra-compaction will be employed.

Advanced technologies to contain and immobilize high-level waste are under development. But, of most significance, programmes are currently in place to demonstrate the adequacy of deep underground disposal of high-level waste. The construction and operation of a geologic repository in the next decade could allay public concerns over the safety as well as cost of disposal. If deemed necessary, the long-lived isotopes (actinides) that are radioactive for many thousands of years can be transmuted in actinide burning reactors. The necessary technology exists for these reactors and their associated chemical separation plants. As already noted, the thorium fuel cycle results in less long-lived isotopes and lower disposal requirements.

Maximizing reactor safety. With more than 430 reactors operating for more than 20 years on average, nuclear power generally has an excellent safety record. But the Chernobyl accident in 1986 demonstrated that a very severe nuclear accident has a potential to cause national and

Fuel and Waste Comparisons

1000-MWe electricity plant in tonnes/year

Nuclear	**Coal***
Fuel: 27t (160t Natural uranium/year)	*Fuel:* 2.6 million t (5 trains of 1400t/day)
Wastes: 35t (high level) 310t (intermediate) 460t (low level)	*Wastes:* 6.5 million t CO_2 900 t SO_2 4500 t NO_x 320,000 t Ash (with 400t toxic heavy metals)

*Equipped with latest pollution abatement technology.

regional radioactive contamination. Although safety and environmental impacts are becoming a key issue for all energy sources, many in the general public perceive nuclear power as particularly and intrinsically unsafe. The safety concerns coupled with the associated regulatory requirements will, in the near term, continue to exert a strong influence on nuclear power development. In order to reduce the magnitude of real and perceived accidents, a number of approaches will be used in new facilities.

Extraordinarily effective barriers (such as double containments) will reduce the likelihood of significant off-site radiological accident consequences to an extremely low level to eliminate the need for emergency action plans. Enhancing the integrity of the reactor vessel and reactor systems will also decrease the likelihood of on-site consequences.

International collaboration will provide reactor and system designs that incorporate globally accepted safety and engineering standards. It will contribute to assuring safety worldwide and encourage country-of-origin licensing as an acceptable basis for national licensing of imported reactors. Plant designs and processes are more intrinsically safe by incorporating passive safety features rather than active protection systems. High temperature gas-cooled reactors that employ ceramic graphite fuel can limit the potential for the release of radioactive material and may emerge as a viable option.

Continued development of a strong global nuclear safety culture brought about by international collaborative efforts aimed at strengthening safety worldwide would contribute to public awareness of the strong international commitment to assuring safety. A wide range of international agreements, non-binding safety standards and international review and advisory services already exists in what is now distinctly seen as an international nuclear safety regime. Highly visible components are the Convention on Nuclear Safety, which entered into force in October 1996, and whose Contracting Parties recently agreed on the review process for the Convention's implementation; and the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management, whose adoption is expected at a Diplomatic Conference this year.

Unquestionably, the most convincing demonstration of safety will be through the safe performance of existing plants and the avoidance of any major incident in the future.

Satisfying key policy needs. Energy independence along with non-proliferation concerns and excess military plutonium are high on the list of policy factors at the national and international level that strongly influence the nuclear option.

In a political world, energy independence through security of energy supply and a balanced mix of energy sources are paramount national interests. With nuclear power, security of supply concerns are lessened as adequate strategic inventories can be relatively easily established with low financial costs. Today's global energy mix has an almost 90% fossil component. Clearly, where indigenous fossil fuel resources are lacking, nuclear energy can contribute substantially to the energy mix as it does in France, the Republic of Korea, and Japan.

The potential for nuclear materials and technologies to be diverted to nuclear weapons production is a valid concern. The international community has recognized the proliferation risks and measures exist to prevent diversion of fissile materials. These include the Treaty on the Non-Proliferation of Nuclear Weapons and associated safeguards agreements with the IAEA, as well as a number of other multilateral agreements. To further reduce the risks of proliferation, design efforts are under way for diversion resistant reactors and fuel cycles that generate fissile material unsuitable for weapons use.

To deal with present stockpiles of military plutonium, proposals exist for their use in mixed oxide fuels in the current generation of water reactors. Employment of a fast breeder reactor strategy would reduce the plutonium stockpile that now exists in spent fuel and over the long term could eventually eliminate its accumulation.

Direction of IAEA programmes related to nuclear power development

Taking into account the current situation of nuclear energy in the world, a stronger initiative on an international level is required to realize the technology's potential benefits. The Agency continues to play a catalytic role in co-ordinating actions, covering the whole range of energy issues, undertaken by Member States and different international or specialized organizations. The IAEA's programmes and activities will be described under the following headings: nuclear power, nuclear fuel cycle, waste management technology and comparative assessment of energy sources.

Underlining the work ahead is a reinforced global commitment to safe nuclear operations through legal agreements, safety standards, and associated expert services. *(See box.)* The declaration of the April 1996 Moscow Summit reiterated that safety is the first priority in nuclear activities. Furthermore, it is to be expected that safety targets will continue to rise and this will require continuous effort and vigilance by the IAEA and its Member States to ensure that adequate levels are maintained.

Nuclear power. The IAEA's efforts in nuclear power will focus on the contribution of nuclear energy to sustainable development, with emphasis on:

- promoting design and operation measures necessary to achieve safe development of nuclear power;
- assisting developing Member States in planning and implementing nuclear power programmes and in improving the management of nuclear power projects and operating plants;
- improving operating performance and reliability of nuclear power plants through sharing of operating experience and information worldwide in all areas, including training and qualification of personnel.

One mechanism used by the IAEA to keep abreast of the technological developments in a given area is the constitution of an international working group (IWG) for that area. *(See box.)* It consists of top experts from different Member States. The IWG meets periodically to review the current status and future directions of activities in the area concerned and advises the Agency on the programme of activities necessary to meet the needs of Member States.

Through the IWGs on advanced reactor technologies, the Agency will encourage an international exchange of information on non-commercial technology and co-operative research. Another important function will be to assist countries in the preservation of key technological data on advanced nuclear power systems. The Agency will also continue to provide a forum for the review of information on the development of innovative nuclear energy systems such as:

- advanced nuclear reactors with passive safety features;
- thorium fueled reactors;
- fast reactors cooled by lead or lead/bismuth;
- accelerator driven and hybrid fusion/fission concepts.

A new area of activities relates to the current need to examine the possibility of civilian use of

Global Framework of Nuclear Safety

Legally binding international agreements and conventions have been adopted and cover a range of subjects. The subjects include:

- ***Civil Liability for Nuclear Damage***
- ***Physical Protection of Nuclear Material***
- ***Early Notification of a Nuclear Accident***
- ***Assistance in the Case of a Nuclear Accident or Radiological Emergency***
- ***Nuclear Safety***
- ***Safety of Spent Fuel Management and Safety of Radioactive Waste Management***

Non-binding common nuclear and radiation safety standards include:

- ***Basic Safety Standards for Radiation Protection***
- ***Safety Fundamentals***
- ***Nuclear Safety Standards Programme***
- ***Regulations for the Safe Transport of Radioactive Materials***
- ***Radioactive Waste Safety Standards***
- ***Safety Guides and Practices***

International Working Groups in Areas of Nuclear Power

- ***Advanced Technologies for Light-Water Cooler Reactors***
- ***Advanced Technologies for Heavy-Water Cooled Reactor***
- ***Fast Reactors***
- ***High Temperature Gas-Cooled Reactors***
- ***Life Management of Nuclear Power Plants***
- ***Nuclear Power Plant Control and Instrumentation***
- ***Nuclear Power Plant Personnel Training and Qualification***
- ***Water Reactor Fuel Performance and Technology***

military nuclear technologies developed for naval and space applications. Another concerns desalination. An important event was the May 1997 International Symposium on Desalination of Seawater with Nuclear Energy in the Republic of Korea which reviewed experience. Results of this symposium will be utilized to define more precisely the IAEA's work in this area.

Nuclear fuel cycle. Among key topics addressed in the recent IAEA nuclear fuel cycle symposium were the comparative assessment of different options for development of the fuel cycle, management of spent fuel and plutonium, and disposal of radioactive waste. The volume of spent fuel in interim storage at both power and research reactors is growing and the long-term storage of spent fuel in ageing facilities will become an increasingly crucial issue regardless of the management option chosen. Identification and mitigation of environmental, health and safety vulnerabilities of ageing spent fuel will be emphasized and activities relating to exchange of information, experience and advice on technical solutions in this area will be expanded.

With regard to management of plutonium from spent fuel and dismantled warheads, there is an increasing interest in additional international measures to address issues related to its production, transport, storage, and disposal.

Waste management technology. The focus of activities relating to radioactive waste management will be on the following:

- collection, assessment and exchange of information on waste management strategies and technologies;
- provision of general technical guidance, assistance in technology transfer, and promotion of international collaboration;
- examination of the long-term prospects of regional waste management facilities to provide new opportunities to developing countries in resolving their waste management problems in a cost-effective manner.

Comparative assessment of different energy sources. The IAEA programme on comparative assessment of sources of energy will focus on:

- comparative assessment of economic, health, and environmental aspects of energy systems and introduction of the results into the process of energy policy formulation and electricity system expansion planning;
- enhancement of the capability of Member States to incorporate health and environmental considerations in the decision making process in the energy sector;
- provision of a basis to define optimal strategies for the development of the energy sector, consistent with the aims of sustainable development.

A key element is the development and dissemination of databases and methodologies for comparative assessment of energy sources in terms of their economic, health and environmental impacts. Consideration will also be given to dealing with energy demand and supply issues outside the electricity sector.

Attaining environmental goals

The world's record of energy use shows that continuing the current dependence on fossil fuels is not sustainable. Nuclear power can play a role in mitigating the detrimental environmental impacts of energy use. With an increased nuclear role, the dominant reactor types to mid-century will be the light- and heavy-water reactors with improved economics and safety systems. High temperature gas-cooled reactors may gain a role particularly for specialized applications. Thorium-fueled reactors would have a marginal role as it is unlikely that the supporting infrastructure for its use will be developed. Efforts will continue to preserve the potential of fast-breeder reactors and they could be introduced gradually by mid-century.

To make nuclear energy more economically competitive, novel financing methods will have to be developed. Moreover, measures to gain public acceptance will be necessary. The adequacy of waste management policies and the disposal of high-level waste will be demonstrated through selection and use of geologically acceptable depositories. To maintain and enhance nuclear power's safety and performance record, there will need to be continued vigilance to improve safety through design, and to implement an effective operational safety culture and international safety agreements.

The IAEA will have to play an increasingly important role in co-ordinating the efforts of Member States and other international organizations in order to realize the potential benefits of nuclear energy for the world's sustainable development. An important element of programmes will be improving regional and international co-operation and sharing of infrastructure facilities, developmental costs, and operational experience to sustain the development of nuclear technology in a safe, reliable, and economic manner. ❐

Nuclear power plant performance: Sustaining initiatives for progress

The performance of nuclear plants has been steadily improving and countries are taking initiatives to ensure continuing progress

by Boris Gueorguiev and K. V. Mahadeva Rao

Nuclear power is a mature part of the energy mix in many countries today. To reinforce its role, national nuclear authorities are placing greater emphasis on improving all aspects of plant performance. Better plant performance will not only yield more efficient production of electricity, but will also generate more confidence in the safety, economic competitiveness, and environmental advantages of nuclear power plants.

One basic indicator of the technical and economic performance of an electricity plant is known as the energy availability factor (EAF). It is the ratio of a plant's net energy generation in a given period, expressed as a percentage of the maximum energy that could have been produced had the plant been operating continuously during that period. Based on data reported to the IAEA's Power Reactor Information System (PRIS), there has been a steady improvement in the EAF for the world's nuclear plants over the past decade. It rose to 76.8% in 1995, up from 70.1% in 1989. *(See graph on page 10).*

Another measure of performance is related to what are called energy losses. The extent to which these can be minimized is an indicator of how well the plant is performing. Energy losses can be either planned (i.e. controlled by management) or unplanned, and they generally are related to outages for refuelling, maintenance, or testing, for example. Over the past three years worldwide, energy losses have been declining at nuclear plants. This is an indication of continuing improvement in the plant's maintenance and management.

Mr. Gueorguiev is Head of the IAEA's Nuclear Power Engineering Section, Division of Nuclear Power and the Fuel Cycle, and Mr. Rao is a staff member in the Section. Other contributors to the article were Mr. Fausto Calori, Nestor Pieroni, Thomas Mazour, Vladimir Neboyan, and Ms. Rejane de Spiegelberg Planer.

Overall, these performance and management improvements largely can be attributed to the process of utilities learning from experience. At the same time, however, various initiatives taken by countries, frequently working through technical programmes of the IAEA, have played a significant role.

National initiatives for improved performance and safety

The focus of many initiatives in the Agency's Member States has been on improvements in operation, maintenance, and management of nuclear power plants. Such improvements also lead to higher levels of safety at these plants. The initiatives may be divided into five areas, as described below:

Increasing production. This includes taking steps to maintain good plant material conditions through the establishment of high expectations and an attitude of zero tolerance towards defects that can be corrected immediately; reducing the duration of planned outages through more effective planning; performing on-line maintenance, where appropriate, to reduce the duration and cost of planned outages; and reducing the frequency of forced outages through measures such as long-range modification/improvement programmes, the use of modern monitoring equipment, training of plant personnel, and feedback of experience from other similar units.

Reducing workload. This includes taking steps to avoid unnecessary regulatory burdens by modifying or deleting redundant requirements; monitoring the condition of plant equipment as a basis for optimizing preventive maintenance; using maintenance monitoring and analysis techniques that identify requirements

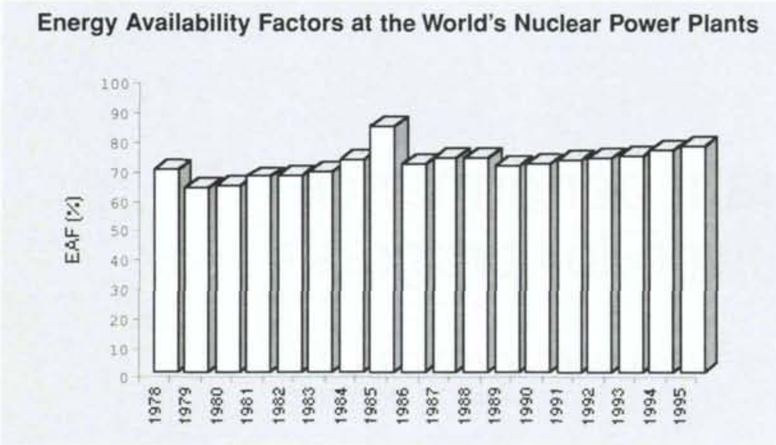


Photo: **Nuclear plants provide about 17% of all the world's electricity. (Credit: Gundremmingen, Germany)**

for equipment according to the safety and operational consequences of failures and the degradation mechanism responsible for them.

Improving work processes. This covers better planning and scheduling over the short, medium and long ranges; using computerized information management systems to support work planning, and maintenance of data on equipment history, cost controls and accounting, including the management of spare parts; applying graduated work controls to provide a means of tailoring the work control process to the significance and complexity of each activity; and post-maintenance testing to check performance of equipment and systems for compliance with design intent.

Improving productivity. This covers human performance through measures such as improving the competence of personnel, tailoring work processes to facilitate staff performance and effective leadership; building better teamwork through the use of multi-disciplinary groups in an organizational structure specifically designed to reduce interfaces and increase job satisfaction and employee morale; sharing of various human resources between different units and sites; sharing of data and experience; sharing of expensive equipment and spare part inventories; and sharing training programmes and facilities; outsourcing/contracting of support services required for maintenance and operation of facilities excluding the main operating and maintenance tasks of a utility; improving management to reduce occupational radiation doses to personnel, minimize contamination, and minimize the volume of radioactive waste arising from maintenance activities.

Measuring performance. This includes establishing performance measures that are objective, observable, measurable and related to results rather than efforts; the use of benchmarking procedures including comparing work performance with that of the best utility, identifying best practices, and implementing a programme to continuously improve performance.

It should be noted that these areas do not explicitly address plant safety and quality assurance, which have justifiably received considerable attention at nuclear utilities. It is recognized that safety and quality are fundamental requirements for the successful utilization of nuclear power and are an inseparable part of each and every activity performed by nuclear power plant personnel. Experience has shown that efforts to improve the efficiency and effectiveness of nuclear plant operation and maintenance programmes, and enhancing the quality of their implementation, have also led to improvements in safety and reliability of plant systems.

Focus of IAEA activities

At the international level, the IAEA has been closely involved in a number of key areas related to the improvement of nuclear plant operations. They include the following types of activities:

Establishment of effective quality assurance programmes. An essential tool for achieving a sustained improvement in plant performance is the establishment of an effective quality assurance (QA) programme. The Agency has updated its safety standards to reflect the modern concept of performance-based QA. The work was done over a five-year period in co-operation with Member States and specifically resulted in the revised Nuclear Safety Standards Quality Assurance Code and its fourteen associated Safety Guides.

During the revision process, the IAEA drew upon the latest experience and considerable resources in countries and at three organizations, namely the European Commission, European Atomic Forum, and the International Standards Organisation. All documents were critically reviewed by the IAEA's Member States before their approval in March 1996.

Management of the procurement activities in a nuclear installation. Managing the services and supplies of contractors requires effective controls to ensure quality and safety. Experience has shown that difficulties can otherwise arise. The topic has been discussed within the framework of IAEA regional technical co-operation projects in Latin America, Asia and the Pacific, and Eastern Europe, and has been pointed out in a number of missions carried out under the IAEA's Operational Safety Review Team (OSART) programme.

In response to needs, the Agency has developed guidance on management practices for controlling quality and safety aspects when employing suppliers/contractors. It also has issued a technical document on the subject for senior managers, line managers, and line supervisors in a nuclear installation.

Plant life management. As plant equipment and major systems grow older, the life management and life extension of a nuclear plant are becoming increasingly important areas of interest. IAEA activities are directed at facilitating the exchange of information and experience for understanding and monitoring the ageing mechanisms affecting the main systems and components, and at providing technical guidance.

An extensive co-ordinated research project on the life management of the reactor pressure vessel primary nozzle was completed in 1996. The work included a review of the ageing process, methods for monitoring the process, measures to mitigate its consequences, and identification of gaps in knowledge. Results of studies enabled identification of different factors affecting the performance of the components. Work now has started on the development of an international database on nuclear power plant life management and major plant components. The first part covers reactor pressure vessel materials, and the first set of data includes about 1500 items on the material properties of such vessels.

Management of the utility-regulatory interface. Managing the interface between the utility and the regulatory body can present difficulties, and improvements are required in many cases. No specific guidance has been available. Because the topic is relevant to plant safety, the IAEA convened an advisory group of experts drawn from nuclear utility managers and regulatory body officials. The group identified a generic set of difficulties, as well as good practices and opportunities for improvement. The good practices relate to the independence of the regulatory body; clarity on the role and functions of the regulatory body; use of a non-prescriptive regulatory approach; well-defined communication procedures; frequent utility-regulator meetings; joint activities in areas such as training and the review of research and development results; and establishment of standards for provision of regulatory services.

Quality assurance in the management of regulatory functions. The application of formal QA requirements to regulatory functions is a sensitive area that needs to be addressed for improving nuclear plant performance. It is receiving progressive attention and was the subject of a meeting of specialists organized by the Agency in 1996.

The main conclusions include the following: Typical difficulties experienced in the discharge of regulatory functions (such as a lack of procedures and standards for the work, unavailability of a system for documentation, and poor communication practices) indicate the need for applying a QA programme. A number of constraints in the application of QA to regulatory functions were identified. They include normal resistance to change; requirements for additional resources (human and financial) for introduction of QA; and a faulty perception that systematic functioning would restrict creativity, judgement, and efficiency. Specialists at the meeting further agreed on the need to develop specific guidance on the subject.

Technical support to operations. A key factor in improving nuclear plant performance is the quality and organization of technical support (TS) services to the operating organization. As guidance on the subject, the IAEA has prepared a technical document presenting good practices in a number of countries. The core functions of TS are to periodically review plant procedures for consistency with management directives, permanent modifications, and changed plant conditions. Reviews should include verification and validation of new or changed procedures as well as records and information systems. TS further should serve as an effective programme to detect deficiencies, determine their root causes, and identify corrective actions to prevent recurrence. It should also be involved in the preparation of licensing documentation, including revisions arising out of modifications.

Apart from day-to-day involvement, TS staff should address long-term issues. These are related to the optimization of plant operations; feedback of operating experience to enable learning from events that happened at the plant and at similar plants elsewhere; monitoring of equipment qualification programmes; and overseeing the plant life extension programme.

Computer and related systems. In the past decade, there has been a growing need to address obsolescence of control and instrumentation systems, improve human performance, and to comply with increasingly stringent regulatory requirements. As a result, nuclear power plants have replaced ageing analogue systems with digital systems and have introduced comprehensive and accessible information database and management systems. These systems support operations and maintenance to achieve an overall improvement in quality assurance and productivity. The advances in information and communication technology have helped utilities operate power plants more efficiently by integrating computer resources and increasing the availability of information to meet the needs of plant staff and corporate business strategy. In response to the current needs for modernization of control and instrumentation, the Agency launched, in 1996, a project aimed at a comprehensive review of modernization issues.

Major goals of using computers in operation and maintenance of nuclear power plants are to improve safety and reduce the risk to capital investment; to reduce the cost of operations and maintenance; to enhance power production; and to increase productivity of employees. Computers provide a number of advantages. They include the ease of introducing complex protective and interlock functions; automatic control of plant conditions that could not otherwise be easily controlled; complex and rapid calculation facilities to allow on-line assessment of reactor conditions leading to improved safety and economy; and availability of video units to display plant conditions, which can reduce control panel size and increase operational effectiveness.

To assist control-room operators, a number of computerized support systems are being used. Examples are displays that graphically show critical parameters or operational data for monitoring. In the maintenance area, computerized support systems have been developed to reduce equipment failures. They allow faster fault detection and diagnosis, and provide the capability to improve planned maintenance of equipment. Other types of systems have been developed to help plan refuelling and to analyze the root causes of events, for example.

In 1995, the IAEA set up a worldwide database on computerized support systems. The first version of a database on operator support systems also was completed in 1996 and distributed to nuclear power plants, design organizations, and other interested national institutions.

Future directions and challenges

Even stronger initiatives at the global level are needed in support of nuclear power development and improved plant performance. Over the near term, the IAEA is planning to emphasize issues of importance to decisions on the role of nuclear energy in national energy plans. Activities will involve national authorities and efforts to enhance regional cooperation to effectively utilize existing expertise and resources.

A central focus will be to support the continuing improvement of the operating performance and reliability of nuclear power plants. This will involve further enhancements of management practices and greater sharing of operating experience and information worldwide. For its part, the IAEA is working to expand its databases related to power reactor operations and plant life management.

Through a co-ordinated research programme, the Agency will also focus on efforts to assure the structural integrity of reactor pressure vessels. This will involve the development of a uniform procedure for testing small specimens to obtain data for analyzing the potential for fractures. Other activities will be directed at the training of nuclear power plant personnel, in light of technology advances and the restructuring and reorganization associated with privatization and downsizing.

Over the past years, the IAEA and nuclear utilities in its Member States have taken a number of positive steps for improving the performance of nuclear power plants, with good results. A major challenge in years ahead will be to ensure that improvements are sustained, and that new initiatives are launched for continuing progress in the economic competitiveness, reliability, and safety of nuclear plants around the world. ❐

Advanced nuclear power plants: Highlights of global development

Building on today's best safety and operational features, new nuclear plants are being designed and introduced in many countries

by
Poong-Eil Juhn, Juergen Kupitz, and John Cleveland

Worldwide, considerable efforts are being made to develop advanced nuclear power plants. Various organizations are involved, including governments, industries, utilities, universities, national laboratories, and research institutes. Expenditures for development of new designs, technology improvements, and the related research for the major reactor types combined is estimated to exceed US $1.5 billion per year.

Through activities within the framework of its nuclear power programme, the IAEA is serving as an international source of objective reference information about the different concepts being developed and the project status, as well as typical development trends throughout the world.

The full spectrum of advanced nuclear power plant designs or concepts covers different types of designs — evolutionary ones, as well as innovative designs that require substantial development efforts. A natural dividing line between these two categories arises from the necessity of having to build and operate a prototype or demonstration plant to bring a concept with much innovation to commercial maturity, since such a plant represents the major part of the resources needed. Designs in both categories need engineering, and may also need research and development (R&D) and confirmatory testing prior to freezing the design of either the first plant of a given line in the evolutionary category, or of the prototype and/or demonstration plant for the second category. The amount of such R&D and confirmatory testing depends on the degree of both the innovation to be introduced and the related work already done, or the experience that can be built upon. This is particularly true for designs in the second category where it is entirely possible that all a concept needs is a demonstration plant, if development and confirmatory testing is essentially completed. At the other extreme, R&D, feasibility tests, confirmatory testing, and a prototype and/or demonstration plant are needed in addition to engineering. *(See box, page 20.)* Different tasks have to be accomplished and their corresponding costs in qualitative terms are a function of the degree of departure from existing designs. In particular, costs jump from the need to build a reactor as part of the development programme.

Overview of water-cooled reactor development programmes

A main focus of development efforts in several industrialized countries is on the design of large light water-cooled reactor (LWR) units, with power outputs well above 1000 megawatts-electric (MWe). They typically aim to achieve certain improvements over existing designs. The alterations and modifications to a specific design are generally kept as small as possible. This is done to take maximum advantage of successful proven design features and components while taking into account feedback of experience from licensing, construction, commissioning and operation of the water-cooled reactor plants currently in operation.

In general, the design improvements span a wide range. Common goals for the new designs are increased reliability, more user-friendly features, better economics, and enhanced safety.

Mr. Juhn is Director of the IAEA's Division of Nuclear Power and the Fuel Cycle. Mr. Kupitz is Head of the Division's Section on Nuclear Power Technology Development, of which Mr. Cleveland is a senior staff member. Also contributing to the article was Mr. Tor Pedersen, a former staff member of the Division.

Advanced light-water reactors (ALWRs). Designs for large ALWRs are being developed in a number of countries. Advanced mid-sized plants are also being developed, in most cases with a great emphasis on the use of passive safety systems and inherent safety features.

United States. Important programmes in development of ALWRs were initiated in the mid-1980s in the United States. In 1984, the Electric Power Research Institute (EPRI), in cooperation with the US Department of Energy and with participation of US nuclear plant designers, initiated a programme to develop utility requirements for ALWRs to guide their design and development. Several foreign utilities have also participated in, and contributed funding, to the programme. Utility requirements were established for large boiling-water reactors (BWRs) and pressurized-water reactors (PWRs) having power ratings of 1200 to 1300 MWe, and for mid-sized BWRs and PWRs having power ratings of about 600 MWe.

In 1986, the US Department of Energy, in cooperation with EPRI and reactor design organizations, initiated a design certification programme for evolutionary plants based on a new licensing process, followed in 1990 by a design certification programme for mid-size plants with passive safety systems. The new licensing process allows nuclear plant designers to submit their designs to the US Nuclear Regulatory Commission (NRC) for design certification. Once a design is certified, the standardized units will be commercially offered, and a utility can order a plant confident that generic design and safety issues have been resolved. The licensing process will allow the power company to request a combined license to build and operate a new plant, and as long as the plant is built to pre-approved specifications, the company can start up the plant when construction is complete, assuming no new safety issues have emerged.

Four advanced reactor designs developed in the United States have been submitted to the NRC for certification under the US Department of Energy ALWR programme. Two large evolutionary plants — the System 80+ of ABB-Combustion Engineering and the ABWR of General Electric — received Final Design Approval in 1994 and Design Certification in May 1997. The 600-MWe AP-600 of Westinghouse is under NRC review and a Final Design Approval is expected by March 1998. Up to mid-1996, the 600-MWe simplified BWR developed by General Electric was also under review, but then the company stopped work on the 600-MWe version and shifted its emphasis to a unit with larger output. The first-of-a-kind engineering programme (FOAKE, the detailed design needed to verify cost and the construction schedule) authorized by the 1992 Energy Policy Act was completed for the ABWR in September 1996, and similar work on the AP-600 is under way with completion scheduled in 1998. The power company in Taiwan, China, recently selected General Electric's ABWR design for two new units slated for operation in 2004.

France and Germany. In Europe, Framatome and Siemens have established a joint company, Nuclear Power International, which is developing a new advanced reactor, the European pressurized-water reactor (EPR), a 1500-MWe plant with enhanced safety features. The basic design will be completed in mid-1997, and the design will be reviewed jointly by the French and German safety authorities. This procedure will provide strong motivation for the practical harmonization of the safety requirements of two major countries, which could later be enlarged on a broader basis. Siemens is also, together with German utilities, engaged in the development of an advanced BWR design, the SWR-1000, which will incorporate a number of passive safety features, for initiation of safety functions, for residual heat removal, and for containment heat removal.

Sweden and Finland. In Sweden, ABB Atom, with involvement of the utility Teollisuuden Voima Oy (TVO) of Finland, is developing the BWR-90 as an upgraded version of the BWRs operating in both countries.

Republic of Korea. In the Republic of Korea, an effort started in 1992 to develop an advanced design known as the Korean Next Generation Reactor (KNGR), a 4000-MWth PWR design. The basic design is currently being developed by the Korea Electric Power Corporation (KEPCO) with support of the Korean nuclear industry. The goal is to complete a detailed standard design by the year 2000.

Russian Federation. In the Russian Federation, design work is under way on the evolutionary V-392, an upgraded version of the VVER-1000, and another design version is being developed in cooperation with the Finnish company Imatran Voima Oy (IVO). Also being developed is a mid-sized plant, the VVER-640 (V-407), an evolutionary design which incorporates passive safety systems, and the VPBER-600, which is a more innovative, integral design. Construction of the first unit of the VVER-640 is planned to start at Sosnovy Bor in 1997. Construction of two

1000-MWe VVERs is being discussed with the People's Republic of China.

Japan. In Japan, the Ministry of Trade and Industry is conducting an "LWR Technology Sophistication" programme focusing on development of future LWRs and including requirements and design objectives. A large, evolutionary 1350-MWe advanced PWR is being developed by Japanese utilities together with nuclear vendors, with construction of a twin unit being planned at the Tsuruga site. In addition, an advanced BWR Improvement and Evolution study was started in 1991. It involves development of a reference 1500-MWe BWR that reflects the accumulated experience in operation and maintenance of BWRs. Also in progress are development programmes for a Japanese simplified BWR (JSBWR) and PWR (JSPWR), projects which involve vendors and utilities. The Japan Atomic Energy Research Institute (JAERI) has been investigating conceptual designs of advanced water-cooled reactors with emphasis on passive safety systems. These are the JAERI Passive Safety Reactor (JPSR) and the System-Integrated PWR (SPWR).

China. In China, the Nuclear Power Institute (Chengdu) is developing the AC-600 advanced PWR, which incorporates passive safety systems for heat removal.

In all of these countries, the advanced LWRs under development incorporate significant design simplifications, increased design margins, and various technical and operational procedure improvements. These include better fuel performance and higher burnup, a better man-machine interface using computers and improved information displays, greater plant standardization, improved constructability and maintainability, and better operator qualification and simulator training.

Heavy-water cooled reactors (HWRs). In addition to light water-cooled reactors, the technology for HWRs has also proven to be economic, safe, and reliable. Approximately 7% of all current operating plants are HWRs. A mature infrastructure and regulatory base has been established in several countries, notably in Canada, the pioneer in the development of the HWR concept. Two types of commercial HWRs have been developed, the pressure tube and the pressure vessel versions, and both have been fully proven. HWRs with power ratings from a few hundred MWe up to approximately 900 MWe are available. The heavy-water moderation yields a good neutron economy and has made it possible to utilize natural uranium as fuel which leads to lower fuel costs compared with LWRs. The amount of fissile material is quite limited, however, and the pressure tube designs are therefore using on-load refuelling to achieve adequate reactivity for the plant operation. The effectiveness of this on-load refuelling has been successfully demonstrated; the annual and lifetime load factors of most of the pressure tube HWRs have been among the best of all commercial reactor types. Safety performance has also proven to be very good.

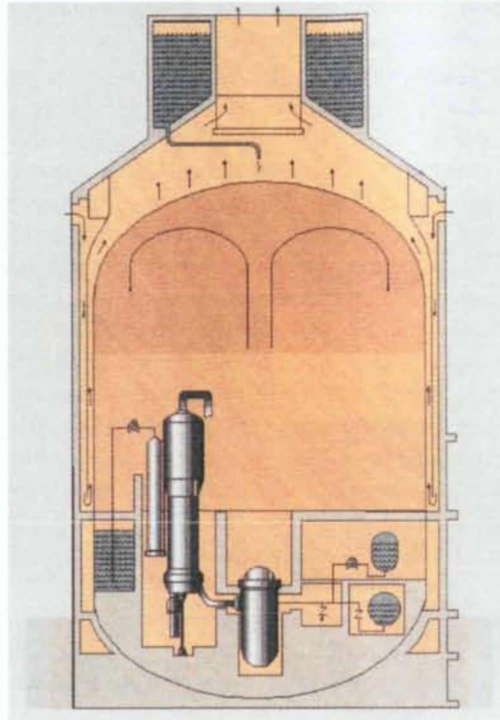
Canada. The continuing design and development programme for HWRs in Canada are primarily aimed at reduction of plant costs and at an evolutionary enhancement of plant performance and safety. Two new 715-MWe CANDU-6 units with improvements over earlier versions of this model are under construction in Qinshan, China. Up-front basic engineering continues on the 935-MWe CANDU-9 reactor, a single unit adaptation of reactor units operating in Darlington, Canada. The two year licensability review by the Canadian Nuclear Safety Commission was completed in January 1997, and found that the CANDU-9 meets the country's licensing requirements. Further studies are being carried out for advanced versions of these reactor models to incorporate further evolutionary improvements and to increase the output of the larger reactor up to 1300 MWe.

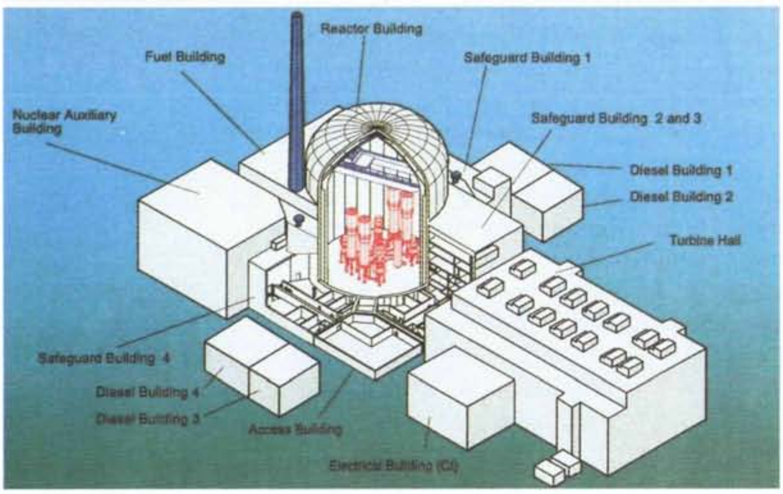
India. Also under development is an advanced 500-MWe HWR in India, and construction of such units is planned. This HWR design takes advantage of experience feedback from the 220-MWe HWR plants of indigenous design operating in India.

Recent important events. Important events in 1996 in the field of water-cooled reactors included the startup of new plants in several countries: the 1130-MWe Genkai-4 PWR, and the first two 1315-MWe Advanced Boiling Water Reactors (ABWRs) at Kashiwazaki Kariwa, in Japan; the first 1455-MWe N4 PWR at Chooz in France; the 650-MWe Cernavoda-1 HWR in Romania; and the 1165-MWe Watts Bar-1 PWR in the United States.

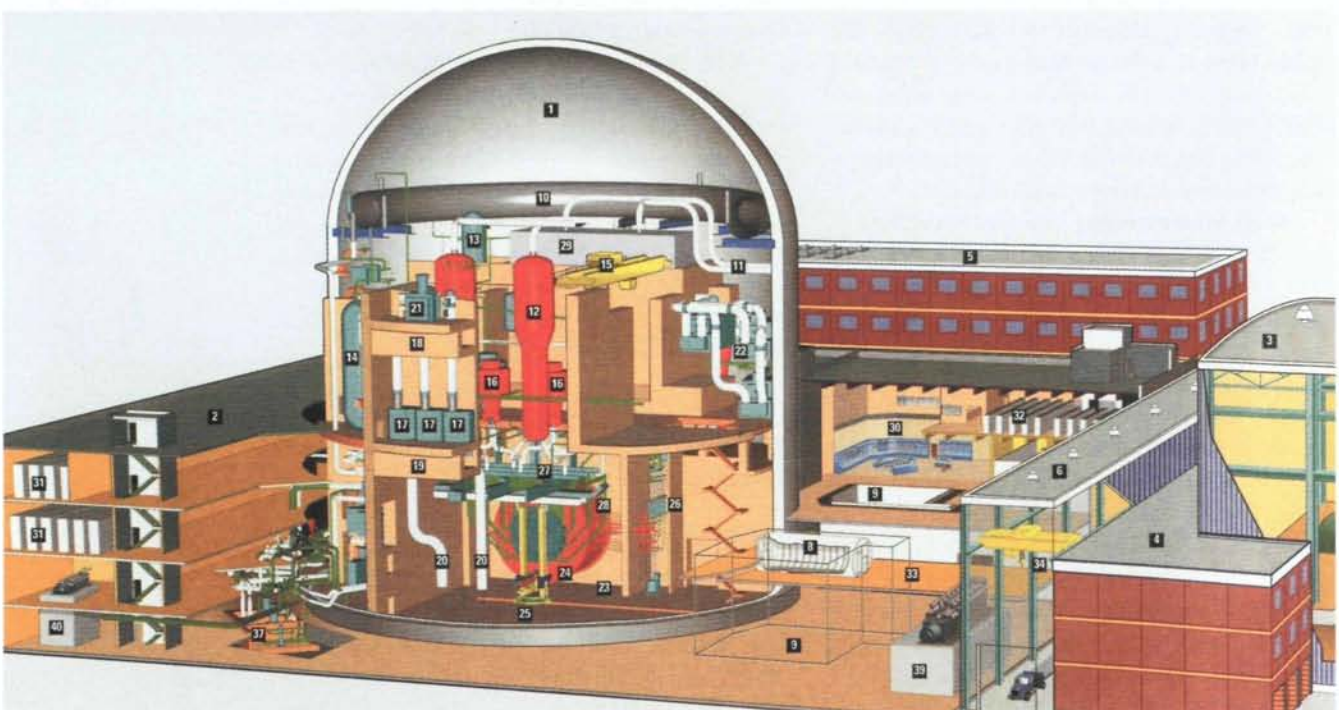
Overview of gas-cooled reactor development programmes

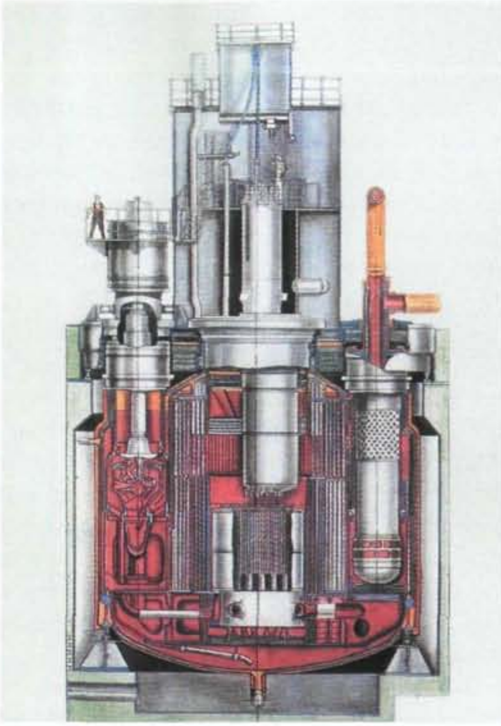
Significant activities are occurring in the development of high-temperature gas-cooled reactors (HTGRs), particularly with regard to the utilization of the gas-cooled reactor to achieve high efficiency in the generation of electricity and in process heat applications. Technological advances in component design

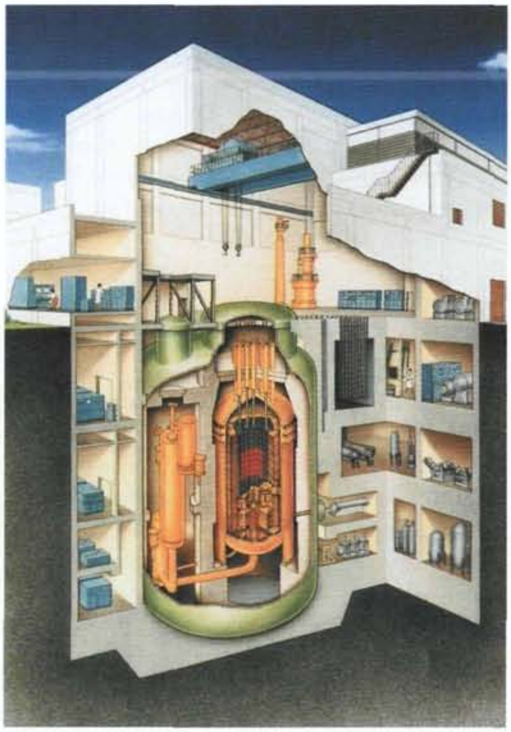




This page: Among advanced reactors being developed worldwide are *(clockwise from top left)* the Advanced Boiling Water Reactor in Japan; the AP-600 in the United States; the Candu-9 heavy-water reactor in Canada; and the European Pressurized Water Reactor jointly by France and Germany. *Facing page:* A schematic of the BN-600 fast-breeder reactor in Russia; schematic of Japan's HTTR; and photo of work on China's HTR-10. *(Credits: TEPCO; Westinghouse; AECL; NPI; Minatom; JAERI)*







and processes — coupled with the international capability to fabricate, test, and procure the components — provides an excellent opportunity for achieving HTGR commercialization.

United Kingdom, Germany, and United States. Gas-cooled reactors have been in operation for many years. In the United Kingdom, nuclear electricity is mostly generated in CO_2-cooled Magnox and Advanced Gas-Cooled Reactors (AGRs). Other countries also have pursued development of high-temperature reactors (HTGRs) with helium as coolant, and graphite as moderator. The 13-MWe AVR reactor has been successfully operated for 21 years in Germany demonstrating application of HTGR technology for electric power production. Other helium-cooled, graphite-moderated reactors have included the 300-MWe Thorium High Temperature Reactor in Germany, and the 40-MWe Peach Bottom and 330-MWe Fort St. Vrain plants in the United States.

South Africa. In South Africa, the large national utility, Eskom, which has an installed generation capacity of about 38,000 MWe, is in the process of performing a technical and economic evaluation of a helium-cooled pebble bed modular reactor. It would be directly coupled to a gas turbine power conversion system for consideration in increasing the capacity of the utility's electrical system.

China and Japan. In China and Japan, test reactors are under construction which will have the capability of achieving core outlet temperatures of 950°C for the evaluation of nuclear process heat applications. Construction of China's High Temperature Reactor (HTR-10) at the Institute of Nuclear Energy Technology (INET) continues with initial criticality anticipated for 1999. This pebble bed reactor of 10

MWth will be utilized to test and demonstrate the technology and safety features of the HTGR. Development of the HTGR by INET is being undertaken to evaluate a wide range of applications. They include electricity generation, steam and district heat production, combined steam and gas turbine cycle operation, and the generation of process heat for methane reforming. The HTR-10 is the first HTGR to be licensed and constructed in China.

The principle focus of Japan's HTGR R&D programme is completion of the High Temperature Engineering Test Reactor (HTTR) at the Japan Atomic Energy Research Institute (JAERI) site in Oarai, Japan. This 30-MWth helium-cooled reactor will be utilized to establish and upgrade the technology for advanced HTGR development, and to demonstrate the effectiveness of selected high temperature heat utilization systems. Fuel loading of the HTTR is scheduled to begin in 1997 with initial criticality anticipated by the end of the year. The start-up physics testing programme for the HTTR will then continue throughout 1998.

Overview of liquid metal-cooled reactor development programmes

Liquid metal-cooled fast reactors (LMFRs) have been under development for many years in several countries. Twenty LMFRs — including five prototypes with electrical output of between 250 and 1200 MWe — have been constructed and operated, accumulating about 280 reactor-years of operating experience.

In most cases the overall experience has been very satisfactory. The restart and stable operation of the first large demonstration fast reactor Superphenix (1200 MWe) in France is an important achievement in LMFR technology. The demonstration fast reactor BN-600 in Russia with a power output of 600 MWe has operated successfully for 16 years with the average load factor being 77%. Considerable efforts have been made in recent years in France, the Russian Federation, Japan, the United States, and India to lower the capital costs of advanced LMFRs. The latest designs of the LMFR, such as the European fast reactor (EFR) project, are close to achieving economic competitiveness with other reactor types.

Significant technology development programmes for LMFRs are proceeding in several countries, notably France (in co-operation with smaller efforts in Germany, the United Kingdom, and other European countries), Japan, India, and the Russian Federation. Activities continue in some other countries at a lower level.

In the near and medium term, the flexibility of LMFRs may be utilized to manage plutonium and radioactive waste as well as to meet other future objectives. Depending on their core geometries and compositions, fast reactors at a given power rating and core size can either increase, maintain, or decrease the inventory of transuranics. Using this flexibility the loading of fast reactors can be variously configurated/composed to produce transuranic conversion ratios (CR) of less or more than one. If the conversion ration is greater than one, the reactor system would become a breeder and generate fissile materials in response to increased nuclear fuel (power) demand. If it is less than one, the fast reactor would become a burner and could decrease the stocks of fissile materials (as well as actinides).

China. In China, the basic research work on LMFRs was started in 1964. Since then and up to 1987, the major work has been on neutronics, thermal hydraulic, and sodium technology. During 1991-92, the conceptual design of the 15-MWe Chinese experimental fast reactor (CEFR) was completed and during 1992-93, the conceptual design was confirmed and optimization studies were carried out. Since 1993 onwards, major work has involved the preparation of a detailed design.

France. In France, the commercial introduction of LMFRs is being postponed. Meanwhile, the application of an additional important aspect of these reactors — to transmute long-lived nuclear waste and to burn plutonium — is being developed. The current programmes on operation of the 1200-MWe Superphenix (SPX) and the 350-MWth Phenix reflect these requirements. One objective of extending the lifetime of the Phenix reactor by another 10 years is to perform the necessary irradiation experiments.

India. In India the fast-breeder test reactor (FBTR) is in operation. Fuel development, material irradiation, and sodium technology are the principal technical programmes. The introduction of FBRs is linked to their economic acceptability. The basic design features are now selected for the 500-MWe Prototype Fast Breeder Reactor (PFBR). The emphasis in 1997-98 will be on detailed design, engineering development, sodium technology, and materials technology. Reduction in construction time is an important target.

Japan. In Japan, the prototype LMFR "Monju" with the capacity of 280-MWe reached initial criticality in April 1994 and was connected to the grid in August 1995. Reactor operation was interrupted in December 1995 due to a leak in the non-radioactive secondary cooling system. The design of a 660-MWe demonstration fast-breeder reactor (DFBR), which is expected to be constructed in the beginning of the next century, is in progress. In addition to this main stream of development work, studies are being performed regarding the development of technology capable of meeting the diverse needs of future society. These needs include the reduction of environmental impacts and the assurance of nuclear non-proliferation, demands that widen the technological options.

Republic of Korea. The Republic of Korea plans to develop the conceptual design of its first fast-breeder reactor, the 330-MWe Kalimer plant, by 2001. Construction is planned to enable achievement of criticality during 2011.

Russian Federation. Russia's experience in the operation of experimental and prototype fast reactors (the BR-10, BOR-60, and BN-600) has been very good. Efforts are directed towards improving safety and reliability and making the LMFRs economically competitive to other energy sources. While these efforts would take some time, the use of LMFRs over the near-term to burn plutonium and minor actinides is foreseen.

United States. In the United States, the government in 1993 stated that federal funding for reactor development was appropriate only for projects with a potential for near-term commercial application. As a result, the advanced LMFR and integral fast reactor (IFR) programmes were halted. However, the General Electric Company continues its significant design and development programme based on the advanced LMFR and IFR technologies, in collaboration with overseas partners.

IAEA activities supporting development of nuclear power technology

As an international forum for exchange of scientific and technical information, the IAEA plays a role in bringing together experts for a worldwide exchange of information about national programmes, trends in safety and user requirements, the impact of safety objectives on plant design, and the co-ordination of research programmes in advanced reactor technology.

Activities in areas of nuclear power technology development are based on the advice of International Working Groups (IWGs). These are committees of leading representatives of national programmes and international organizations for each major type of reactor.

To support its information exchange function, the IAEA has recently prepared two technical documents — *Status of Advanced Light Water Reactor Designs* and *Fast Reactor Database*. In 1997, topics that will be addressed include improvements in reactor system components and technologies for improving availability and reliability of current and future reactors.

Enhancing communication. Terms such as evolutionary designs, passive designs, and innovative designs have been widely used in describing advanced nuclear power plants, generally without definition and sometimes with usages inconsistent with each other. In view of the importance of communication to the public, and the technical community in general, consistency and international consensus are desirable with regard to the terms used to describe various categories of advanced designs.

In 1991, drawing on advice from reactor design organizations, research institutes, and government organizations, the IAEA issued a document entitled *Safety Related Terms for Advanced Nuclear Power Plants* that is being widely used. More recently, using the same approach to obtain advice from involved parties, the IAEA published *Terms for Describing New Advanced Nuclear Power Plants*. The document's specific purpose is to clarify the meaning of terms by drawing distinctions between design stages reflecting the maturities of designs; for example, whether they are of a developmental nature with some yet untested features or whether they are evolutionary in the sense of retaining many proven features of existing plants.

Co-operative research. The IWGs advise the IAEA to establish international co-operative research programmes in areas of common interest. These co-operative efforts are carried out through Co-ordinated Research Programmes (CRPs), which typically are three to six years in duration, and often involve experimental activities. Such CRPs allow a sharing of efforts on an international basis and benefit from the experience and expertise of researchers from the participating institutes.

As an example, the IAEA has co-ordinated work to collect and systematize a database of thermophysical properties for a broad spectrum of light- and heavy-water reactor materials over a wide range of temperatures; the database has been published. For liquid metal-cooled reactors, the results of co-operative activities on

Advanced design

Different types of new nuclear plants are being developed today that are generally called advanced reactors. In general, an advanced plant design is a design of current interest for which improvement over its predecessors and/or existing designs is expected. Advanced designs consist of evolutionary designs and designs requiring substantial development efforts. The latter can range from moderate modifications of existing designs to entirely new design concepts. They differ from evolutionary designs in that a prototype or a demonstration plant is required, or that insufficient work has been done to establish whether such a plant is required.

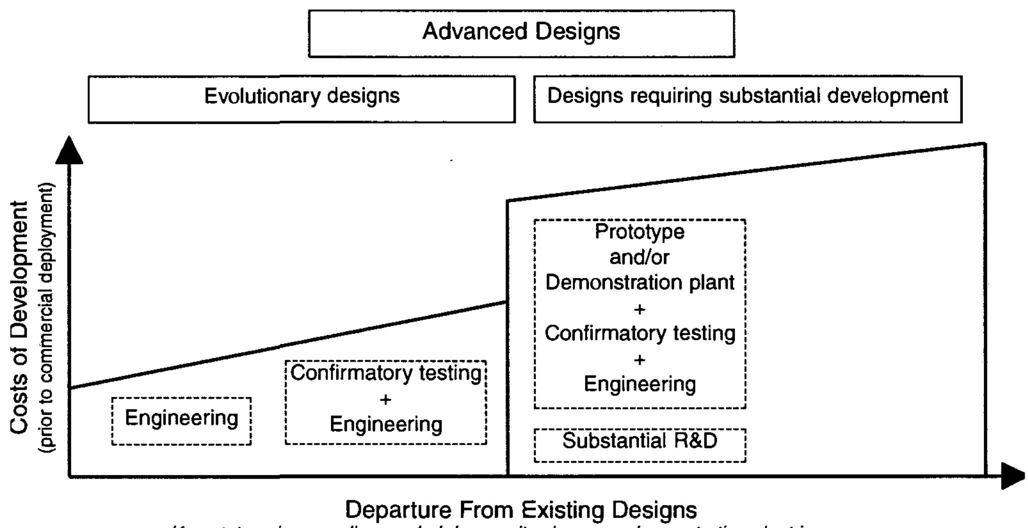
Evolutionary design

An evolutionary design is an advanced design that achieves improvements over existing designs through small to moderate modifications, with a strong emphasis on maintaining proven design features to minimize technological risks. The development of an evolutionary design requires at most engineering and confirmatory testing.

Innovative design

An innovative design is an advanced design which incorporates radical conceptual changes in design approaches or system configuration in comparison with existing practice. Substantial R&D, feasibility tests, and a prototype or demonstration plant are probably required.

Efforts and development costs for advanced designs versus departure from existing designs



(A prototype is normally a scaled down unit, whereas a demonstration plant is a more substantial plant that can be as large as full size.)

material behaviour also have been published recently. In other co-operative programmes, the IAEA is establishing sets of thermohydraulic relationships for water-cooled reactors and liquid metal-cooled reactors appropriate for use in analyzing reactor performance and safety. In the field of gas-cooled reactors, the principle focus has been on the four specific technical areas which are predicted to provide advanced HTGRs with a high degree of safety, but which must be proven. These technical areas are: the safe neutron physics behaviour of the reactor core; reliance on ceramic coated fuel particles to retain fission products even under extreme accident conditions; the ability of the designs to dissipate decay heat by natural heat transport mechanisms, and the safe behaviour of the fuel and reactor core under chemical attack (air or water ingress). Activities in HTGR applications focus on design and evaluation of heat utilization systems for the Japanese HTTR.

All these activities are indicative of global co-operation for the development of advanced types of nuclear power reactors. As countries move ahead with plans, and new plants are introduced, further enhancements can be expected in areas of plant economics, reliability, and safety. Through its International Working Groups on advanced reactors, the IAEA will be encouraging the international exchange of information on non-commercial technology and co-operative research. It will also assist countries in harmonizing user requirements, and in the preservation of key technological data on advanced nuclear power systems. ❐

Nuclear power applications: Supplying heat for homes and industries

More countries are interested in applying smaller sized nuclear reactors to help meet industrial and urban heating needs

by Bela J. Csik and Juergen Kupitz

When the first nuclear power reactor at Calder Hall in the United Kingdom came into commercial operation in October 1956, it provided electricity to the grid and heat to a neighboring fuel reprocessing plant. After more than 40 years, the four 50 megawatt-electric (MWe) Calder Hall units are still in operation. In Sweden, the Agesta reactor provided hot water for district heating to a suburb of Stockholm for a decade, starting in 1963.

These examples show a side of nuclear energy that is unfamiliar to many people — its capacity to deliver heat for industrial processes and urban needs. Such applications started at a very early date, practically at the same time when nuclear power reactors were first applied to electricity generation.

Since these early days of nuclear power development, the direct use of heat generated in reactors has been expanding. Countries such as Bulgaria, Canada, China, the Czech Republic, Germany, Hungary, India, Japan, Kazakstan, Russia, Slovakia, Sweden, Switzerland, and Ukraine have found it convenient to apply nuclear heat for district heating or for industrial processes, or for both, in addition to electricity generation. Though less than 1% of the heat generated in nuclear reactors worldwide is at present used for district and process heating, there are signs of increasing interest in these applications.

The direct use of nuclear heat is nothing new. After all, the result of the nuclear fission process is the generation of heat within the reactor. The heat is removed by the coolant circulating through the core, that can then be applied to the generation of electricity or used in providing hot water or steam for industrial or space heating purposes. There are, however, substantial differences between the properties and applications of electricity and of heat, as well as between the markets for these different forms of energy. These differences as well as the intrinsic characteristics of nuclear reactors are the reasons why nuclear power has predominantly penetrated the electricity market and had relatively minor applications as a direct heat source.

Mr. Csik is a senior staff member in the IAEA's Section on Nuclear Power Technology Development, of which Mr. Kupitz is the Section Head.

The energy market

About 33% of the world's total energy consumption is currently used for electricity generation. This share is steadily increasing and is expected to reach 40% by the year 2015. Of the rest, heat consumed for residential and industrial purposes, and the transport sector constitute the major components, with the residential and industrial sectors having a somewhat larger share. Practically the entire heat market is supplied by burning coal, oil, gas, or wood.

Overall energy consumption is steadily increasing and this trend is expected to continue well into the next century. Conservation and efficiency improvement measures have in general reduced the rate of increase of energy consumption, but their effect is not large enough to stabilize consumption at current values.

A modest increase in the generation of nuclear electricity is expected during the next couple of decades. In the transport sector, practically no application of nuclear energy is foreseen, except indirectly through the increased use of electricity.

The heat market is an open challenge. Though nuclear energy has been used to supply a portion of the heat demand, it has not yet achieved significant penetration. How far and how fast it could capture part of this market will depend mainly on how the characteristics of nuclear reactors can be matched with the characteristics of the heat market, in order to successfully compete with alternative energy sources.

Characteristics of the heat market

Transport of heat is difficult and expensive. The need for a pipeline, thermal isolation, pumping, and the corresponding investments, heat losses, maintenance, and pumping energy requirements make it impractical to transport heat beyond distances of a few kilometers or, at most, some tens of kilometers. There is also a strong size effect. The specific costs of transporting heat increase sharply as the amount of heat to be transported diminishes. Compared to heat, the transport of electricity from where it is generated to the end-user is easy and cheap, even to large distances measured in hundreds of kilometers.

The residential and the industrial sectors constitute the two major components of the overall heat market. Within the residential sector, while heat for cooking has to be produced directly where it is used, the demand for space heating can be and is often supplied from a reasonable distance by a centralized heating system through a district heating transmission and distribution network serving a relatively large number of customers.

District heating. District heating networks generally have installed capacities in the range of 600 to 1200 megawatt-thermal (MWth) in large cities, decreasing to approximately 10 to 50 MWth in towns and small communities. Exceptionally, capacities of 3000 to 4000 MWth can be found. Obviously, a potential market for district heating only appears in climatic zones with relatively long and cold winters. In western Europe, for example, Finland, Sweden, and Denmark are countries where district heating is widely used, and this approach is also applied in Austria, Belgium, Germany, France, Italy, Switzerland, Norway, and the Netherlands, though to a much lesser degree. The annual load factors of district heating systems depend on the length of the cold season when space heating is required, and can reach up to about 50%, which is still way below what is needed for base load operation of plants. Also, to assure a reliable supply of heat to the residences served by the district heating network, adequate back-up heat generating capacity must be provided. This implies the need for redundancy and generating unit sizes corresponding to only a fraction of the overall peak load. The temperature range required by district heating systems is around 100 to 150° C.

In general, the district heating market is expected to expand substantially. Not only because it can compete economically in densely populated areas with individual heating arrangements, but also because it offers the possibility of reducing air pollution in urban areas. While emissions resulting from the burning of fuel can be controlled and reduced up to a point in relatively large centralized plants, this is not practical in small individual heating installations fueled by gas, oil, coal, or wood.

Industrial processes. Within the industrial sector, process heat is used for a very large variety of applications with different heat requirements and with temperature ranges covering a wide spectrum. While in energy intensive industries the energy input represents a considerable fraction of the final product cost, in most other processes it contributes only a few percent. Nevertheless, the supply of energy has an essential character. Without energy, production would stop. This means that a common feature of practically all industrial users is the need for assurance of energy supply with a very high degree of reliability and availability, approaching 100% in particular for large industrial installations and energy intensive processes.

Regarding the power ranges of the heat sources required, similar patterns are found in most industrialized countries. In general, about half of the users require less then 10 MWth and another 40% between 10 and 50 MWth. There is a steady decrease in the number of users as the power requirements become higher. About 99% of the users are included in the 1 to 300 MWth range, which accounts for about 80% of the total energy consumed. Individual large users with energy intensive industrial processes cover the remaining portion of the industrial heat market with requirements up to 1000 MWth, and exceptionally even more. This shows the highly fragmented nature of the industrial heat market.

The possibility of large-scale introduction of heat distribution systems supplied from a centralized heat source — which would serve several users concentrated in so-called industrial parks — seems rather remote at present, but could be the trend on a long term. Contrary to district heating, the load factors of industrial users do not depend on climatic conditions. The demands of large industrial users usually have base load characteristics.

The temperature requirements depend on the type of industry, covering a wide range up to around 1500° C. The upper range above 1000° C is dominated by the iron/steel industry. The lower range up to about 200 to 300° C includes industries such as seawater desalination, pulp and paper, or textiles. Chemical industry, oil refining, oil shale and sand processing, and coal gasification are examples of industries with temperature requirements of up to the 500 to 600° C level. Non-ferrous metals, refinement of coal and lignite, and hydrogen production by water splitting are among applications that require temperatures between 600 and 1000° C.

All industrial users who require heat also consume electricity. The proportions vary according to the type of process, where either heat or electricity might have a predominant role. The demand for electricity can either be supplied from an electrical grid, or by a dedicated electricity generating plant. Co-generating electricity and heat is an attractive option. It increases overall energy efficiency and provides corresponding economic benefits. Co-generation plants, when forming part of large industrial complexes, can be readily integrated into an electrical grid system to which they supply any surplus electricity generated. In turn, they would serve as a back-up for assurance of electricity supply. Such arrangements are often found to be desirable.

Characteristics of nuclear heat sources

From the technical point of view, nuclear reactors are basically heat generating devices. There is plenty of experience of using nuclear heat in both district heating and in industrial processes, so the technical aspects can be considered well proven. There are no technical impediments to the application of nuclear reactors as heat sources for district or process heating. In principle, any type and size of nuclear reactor can be used for these purposes.

Potential radioactive contamination of the district heating networks or of the products obtained by the industrial processes is avoided by appropriate measures, such as intermediate heat exchanger circuits with pressure gradients which act as effective barriers. No incident involving radioactive contamination has ever been reported for any of the reactors used for these purposes.

Regarding the temperature ranges, up to about 300° C are obtained in light- and heavy-water reactors, up to 540°C in liquid metal-cooled fast reactors, up to 650°C in advanced gas-cooled reactors, and up to about 1000° C in high temperature gas-cooled reactors.

For applications to district or process heating, there are basically two options. Co-generation of electricity and heat, and heat-only reactors. Co-generation has been widely applied, while there is not much experience in heat-only reactors. In principle, any amount of heat can be extracted from co-generation reactors, subject to design limitations. Whatever heat is not needed to supply the heat demand can be used for electricity generation, which means a high degree of flexibility. Heat-only reactors, on the other hand, have only one objective, as they are not intended for generating electricity.

The availability of nuclear reactors is, in general, similar to fossil-fuelled power plants. As shown by experience, availability factors of 70% to 80% or even 90% can be achieved. The frequency and duration of unplanned outages can be kept very low with good preventive and predictive maintenance. Availability and reliability of a reactor, however, can never reach the nearly 100% levels required by most large heat users. Consequently, as for fossil-fueled heat sources, redundancy is needed. Multiple unit co-generation power plants, modular designs, or back-up heat sources are suitable solutions.

Nuclear reactors are capital intensive. The influence of the fixed cost component is predominant in the final cost of energy. Therefore, base-load operation with load factors as high as achievable is needed for competition with alternative sources. This is only possible when the demand of the heat market to be supplied has base-load characteristics, or when the combined electricity and heat market enables overall base-load operation of a co-generation plant.

Nuclear reactors can be technically proven, safe, reliable and environmentally clean energy sources, but for commercial deployment they also have to be economically competitive with alternative energy sources. Compared to fossil-fuelled sources, nuclear reactors are characterized by higher investment costs compensated by lower fuel costs. The penetration of nuclear power into the electricity market would not have been possible without having fulfilled the condition of economic competitiveness. Even with prevalent low fossil fuel price levels, nuclear power has retained its competitive position in most parts of the world. Should fossil fuel prices increase, as is expected to occur, the economically competitive position of nuclear power, both for electricity generation and for heat supply, will improve.

Due to the size effect, nuclear economics are, in general, improved for larger units. This has led to the development and predominant deployment of large-size reactors in industrialized countries with very large interconnected electrical grid systems. Nevertheless, there has been and there continues to be a market for small- and medium-sized power reactors (SMRs). Current design SMRs are not scaled down versions of large commercial reactors, and they are intended to be economically competitive.

Siting of nuclear plants has become a major issue, even in those countries which are proceeding with their nuclear programmes by initiating new projects. Building additional units at existing nuclear sites has been standard practice lately, and opening up new sites for nuclear plants are a rare occurrence. Economic factors promote siting as close as possible to load centers even for electricity generating power plants. For co-generation or heat-only reactors, this is practically a necessary condition to be fulfilled. The NIMBY (not in my back yard) syndrome, however, is an important factor affecting site selection. It promotes a trend to choose remote but accessible locations, in order to avoid potential conflicts and opposition. Remote siting far from densely populated areas makes it also easier to comply with regulatory requirements, which are getting more and more demanding. Advanced reactor designs, in particular in the SMR range with improved safety features, could be perceived as acceptable for close siting by the public. They also could more easily meet regulatory requirements and could maintain heat transmission costs at reasonable levels.

In nuclear power, unlike in many industrial undertakings, the long-term viewpoint is predominant. The planning, design, project preparatory activities, and licensing takes years to be completed for any nuclear reactor. Reactors are designed and built to last for about 40 years or more, and to achieve the economic benefits expected, they have to be operated with high load factors during their economic lifetime. There are also infrastructure requirements, which require time and considerable development efforts, if not already available. These efforts are only justifiable under a long-term perspective directed to a nuclear programme.

Prospects for nuclear heat applications

The technical viability of employing nuclear heat sources for district heating or for industrial processes has existed since the very start of nuclear development. A substantial penetration into the commercial heat market, however, has not yet taken place. Prospects will mainly depend on where and how the demand characteristics of the heat market can be matched by what nuclear reactors are able to offer.

District heating market. For the district heating market, co-generation nuclear power plants are one of the supply options. In the case of medium to large nuclear reactors, due to the limited power requirements of the heat market and the relatively low load factors, electricity would be the main product, with district heating accounting for only a small fraction of the overall energy produced. These reactors, including their siting, would be optimized for the conditions pertaining to the electricity market, district heating being, in practice, a byproduct. Should such power plants be located close enough to population centers in cold climatic regions, they could also serve district heating needs. This has been done in Russia, Ukraine, the Czech Republic, Slovakia, Hungary, Bulgaria, and Switzerland, using up to about 100 MWth per power station. Similar applications can be expected for the future wherever similar boundary conditions exist.

For small co-generation reactors corresponding to power ranges of up to 300 MWe and 150 MWe, respectively, the share of heat energy for district heating would be larger. But electricity would still be expected to constitute the main product, assuming base-load operation, for economic reasons. The field of application of these reactors would be similar to the case of medium or large co-generation reactors. Additionally, however, they could also address specific objectives, such as the energy supply of concentrated loads in remote and cold regions of the world.

Heat-only reactors for district heating are another option. Such applications have been implemented on a very small scale (a few MWth) as experimental or demonstration projects. Construction of two units of 500 MWth was initiated in Russia in 1983-85, but later interrupted. There are several designs being pursued, and it is planned to start construction of a 200 MWth unit soon in China. Clearly the potential applications of heat-only reactors for district heating are limited to reactors in the very small size range. These reactors are designed for siting within or very close to population centers so that heat transmission costs can be minimal. Even so, economic competitiveness is difficult to achieve due to the relatively low load factors required, except in certain remote locations where fossil fuel costs are very high and the winter is very cold and long.

In summary, the prospects for nuclear district heating are real, but limited to applications where specific conditions pertaining to both the district heating market and to the nuclear reactors can effectively be met. The prospects for co-generation reactors, especially in the SMR range, seem better than for heat-only reactors, mainly because of economic reasons.

Industrial process heat. The characteristics of the market for process heat are quite different from district heating, though there are some common features, particularly regarding the need for minimal heat transport distance. Industrial process heat users, however, do not have to be located within highly populated areas, which by definition constitute the district heating market. Many of the process heat users, in particular the large ones, can be and usually are located outside urban areas, often at considerable distances. This makes joint siting of nuclear reactors and industrial users of process heat not only viable, but also desirable in order to drastically reduce or even eliminate the heat transport costs.

For large size reactors, the usual approach is to build multiple unit stations. When used in the co-generation mode, electricity would always constitute the main product. Such plants, therefore, have to be integrated into the electrical grid system and optimized for electricity production. For reactors in the SMR size range, and in particular for small and very small reactors, the share of process heat generation would be larger, and heat could even be the predominant product. This would affect the plant optimization criteria, and could present much more attractive conditions to the potential process heat user. Consequently, the prospects of SMRs as co-generation plants supplying electricity and process heat are considerably better than those of large reactors.

Several co-generation nuclear power plants in operation already supply process heat to industrial users. The largest projects implemented are in Canada (Bruce, heavy-water production and other industrial/agricultural users) and in Kazakstan (Aktau, desalination). Other power reactors which currently produce only electricity, could be converted to co-generation. Should there be a large process heat user close to the plant interested in receiving this product, the corresponding conversion to co-generation would be technically feasible. It would, however, involve additional costs, which would have to be justified by a cost/benefit analysis. Some such conversion projects could be implemented but, in general, prospects for this option seem rather low.

Installing a new nuclear co-generation plant close to an existing and interested industrial user has better prospects. Even better would be a joint project whereby both the nuclear co-generation plant and the industrial installation requiring process heat are planned, designed, built, and finally operated together as an integrated complex.

Current and advanced light- or heavy-water reactors offer heat in the low temperature range, which corresponds to the requirements of several industrial processes. Among these, seawater desalination is presently seen as the most attractive application. Other types of reactors, such as liquid metal-cooled fast reactors and high temperature gas-cooled reactors can also offer low temperature process heat, but in addition, they can cover higher temperature ranges. This extends their potential field of application. These reactors still require substantial development in order to achieve commercial maturity. Should they achieve economic competitiveness as expected, their prospects seem to be promising in the medium to long term, especially for high temperature industrial applications.

Heat-only reactors have not yet been applied on an industrial/commercial scale for the supply of process heat. Several designs have been developed and some demonstration reactors have been built. Economic competitiveness seems to be an achievable goal according to many studies which have been performed, but this is something yet to be proven in practice. The potential market for such heat-only reactors would be limited to the very small size range, i.e. below about 500 MWth.

The prospects for applying nuclear energy to district and process heating are closely tied to the prospects of deploying SMRs. A recent market assessment for SMRs found that 70 to 80 new units are planned in about 30 countries up to the year 2015. It was also found that about a third of these units are expected to be applied specifically to nuclear desalination. Of the rest, a substantial share could very well supply heat in addition to electric energy, while a few are expected to be heat-only reactors. ❐

Nuclear energy applications: Desalting water from the sea

Through IAEA-supported studies, options have been identified for demonstrating the practical use of nuclear desalination systems

by Toshio Konishi

Water resources in many parts of the world are not sufficient to meet the needs of people living there. In many cases, natural sources of fresh water supply are threatened by pollution and increasing salinity. At the same time, the demand for clean, potable water is growing, particularly in areas of high population growth.

Part of the answer to such pressing water problems may come from the sea's abundant resources. Desalination is one of the most promising alternatives for supplying potable water, and nuclear power plants could be an important part of the picture. The world's collective desalination capacity has increased steadily in the past decades, a trend expected to continue into the next century, and more countries are interested in using nuclear energy to desalt seawater.

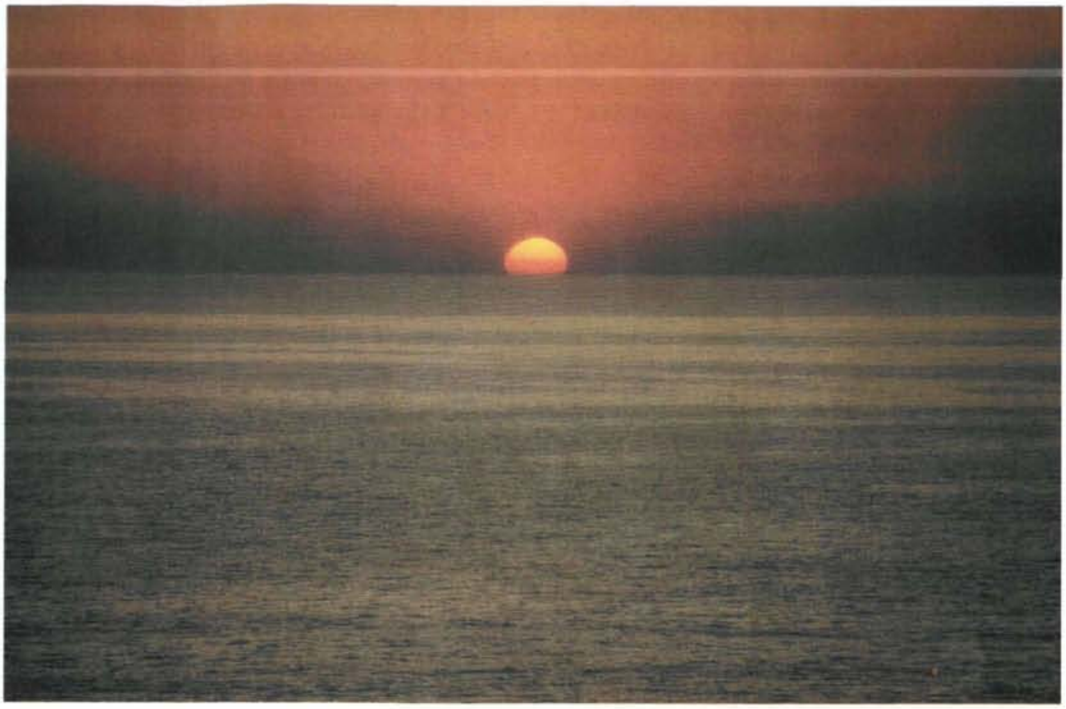
The reasons behind nuclear power's use for electricity generation also apply to its potential use for seawater desalination. These reasons are, for example, economic competitiveness in areas which lack cheap hydropower or fossil fuel resources, energy supply diversification, conservation of fossil fuel resources, the promotion of technological development, and environmental protection by avoiding emissions of air pollutants and greenhouse gases.

The IAEA surveyed the feasibility of using nuclear energy for seawater desalination as early as the 1960s and 1970s. But at that time, interest was directed mainly at its use for electricity generation, district heating, and industrial process heat. Since 1989, however, the IAEA's Member States have shown renewed interest in nuclear desalination, adopting a number of resolutions on the subject.* With this support, a growing number of IAEA Member States and international organizations have participated in meetings, and provided relevant expertise and support. The assistance and support, involving more than 20 Member States, has included the provision of expert services and funds. Additionally, the IAEA has performed studies to assess the technical and economic potential of nuclear reactors for seawater desalination.

One study, *The Potential for Nuclear Desalination as a Source of Low Cost Potable Water in North Africa*, was completed in 1996 and published as a technical document (IAEA TECDOC-917). It analyzed the electricity and potable water demands and the available energy and water resources in five countries: Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, and Tunisia. The scope included the selection of representative sites, analysis of various combinations of energy sources and desalination processes appropriate for each site, economic factors, financial aspects, local participation, infrastructure requirements, and institutional and environmental aspects. Other generic studies described in another IAEA publication (TECDOC-666) examined costs for different types of applications. These assessments have shown that nuclear seawater desalination could be technically and economically feasible.

Mr. Konishi is a staff member in the IAEA Division of Nuclear Power and the Fuel Cycle, Nuclear Technology Development Section.

*Nuclear desalination is taken here to mean the production of potable water from seawater in an integrated complex in which both the nuclear reactor and the desalination system are located on a common site, the relevant facilities and services are shared, and the energy used for the desalination process is produced by the nuclear reactor.



Taking the salt out of seawater takes energy.

Assessing global experience

Recent IAEA activities* have focused on helping countries to assess the economic feasibility of using nuclear plants for desalination. Methods have been developed that enable site-specific economic evaluations. A computer programme is available for countries to use in such analyses, and some experts already been trained on the program's use. Now being envisaged is the development of a more detailed computer programme for allocating the costs of dual-purpose plants and determining their optimum coupling.

In 1995, the IAEA convened an advisory group of experts to review global experience with coupling nuclear energy plants and heat application systems like district heat networks and desalination processes. About 500 reactor years of operational experience from nuclear co-generation and heat-only reactors are now available in twelve countries.

Nuclear energy has been used for seawater desalination at locations in Japan and in Kazakstan. While in Japan the desalination plants are mostly for on-site water supply, the Aktau desalination complex in Kazakstan supplies water to a nearby population center.

While most industrialised countries are favouring large nuclear power stations for domestic application, there is a growing interest in smaller reactors (SMRs) in several Member States. These plants would fit better to smaller and weaker electricity grids and would better match the rates of projected growth in power demand. Most countries which are suffering from potable water shortages have grids for which SMRs could be an appropriate choice for electricity generation and for desalting seawater. An SMR survey, published by the IAEA in a technical document (TEC-DOC-881), has found that many different SMR types of plants have been designed. Vendors have offered these reactors as possible options for coupling to desalination processes.

Identifying options

In line with resolutions of the IAEA General Conference, the Agency has further focused on activities related to identifying options for nuclear desalination and demonstrating the technology. A demonstration programme would aim to build confidence, through the design, construction, operation, and maintenance of appropriate facilities, that nuclear desalination can be technically and economically feasible,

*For an option to be "practical", it was regarded to have fulfilled the following conditions: there is no technical impediment to implementation and a suitable site exists; it is technically feasible to be implemented on a certain predetermined schedule; and the investment cost can be estimated within an acceptable range. Nuclear and desalination technologies have promising prospects for future commercial application.

while meeting established safety and reliability criteria. Toward this end, a two-year "Options Identification Programme (OIP)" was initiated with participation of representatives from interested Member States.

The purpose of the OIP is to select from a wide range of possible choices in terms of desalination technologies and reactor types the few most practical candidates for demonstration.* The demonstration options are based on reactor and desalination technologies which are themselves readily available without further development being required at the time of the demonstration.

In the course of identifying practical options for demonstration, the list of available reactors was reviewed and several reactors were identified as being most appropriate. A set of screening criteria based on design and licensing status were used as a filter. Applying them, the reactor technologies currently available or which might become available within a period of approximately the next ten years were identified. Additional screening factors were then considered, which ruled out some options. These included various reactor designs which are not commercially offered; liquid metal-cooled reactors and high temperature gas-cooled reactors, which are unlikely to be commercially available in the near term; large reactors, which are unlikely to fit the electricity grids of most countries facing water shortages; small reactors which currently appear to be economically less competitive (however, they may be feasible at sites with low water demand and where alternative systems for potable water production are also expensive); and boiling-water reactors, which are likely to require installation of additional systems in order to prevent radioactive release to the heat recipient systems.

Consideration was also given to desalination technologies suitable for coupling to a nuclear reactor. Desalination by the processes of reverse osmosis (RO) and multi-effect distillation (MED) appear to be most promising, due to relatively low energy consumption and investment costs, as well as high reliability. Originally, the multi-stage flash (MSF) process was also considered as a candidate. However, the MED process has a lower energy consumption and appears to be less sensitive to corrosion and scaling than the MSF process. Also, its partial load operability is more flexible. Therefore, MSF has been excluded as a candidate, having no inherent advantages over MED.

The desalination processes for demonstration do not need to be implemented at the level of large-scale commercial production. Two or three trains or units could provide design and operational performance characteristics which are fully representative of larger scale production facilities, as the larger plants are simply multiple trains or units operated in parallel.

When combining a nuclear reactor and a desalination process to form an integrated facility, their compatibility was taken into account in the selection process. Scheduling, infrastructure, and investment requirements were also considered for their significance in identifying practical options for demonstration.

As a result of this screening, three options were identified as recommendable, practical candidates for nuclear desalination demonstration. These options use well-proven water cooled reactors and desalination technologies.

Option 1: RO desalination in combination with a nuclear power reactor being constructed or in an advanced design stage with construction expected in the near term. The preferred capacity of the reactor would be in the medium-size range. Two or three RO trains, up to 10,000 cubic meters per day each, would provide a suitable demonstration. A newly constructed reactor would offer the best opportunity to fully integrate the RO and reactor systems, including feedwater preheating and the optimization of system design. Such demonstration could readily be extrapolated to larger scale commercial production facilities.

Option 2: RO desalination, as above, in combination with a currently operating reactor. Some minor design modifications may be required to the periphery of the existing nuclear system. Advantages include a short implementation period, a broad choice of reactor sizes, and the availability of nuclear infrastructures. A reactor in the medium-size range would be preferred, as it provides a system close to that which would most likely be used in commercial production facilities.

Option 3: MED desalination in combination with a small reactor. This would be suitable for demonstration of nuclear desalination for capacities of up to 80,000 cubic meters per day.

It has been concluded that these demonstration options could be implemented, if there is interest from investors. The investment required would be in the order of US $25 million to $50 million for the RO options and US $200 million to $300 million for the MED option, the latter including the cost of the reactor.

The process of identifying and characterizing demonstration candidates during the OIP required considering many issues which must be addressed for the demonstration of nuclear desalination as well as for commercial deployment. A demonstration programme is intended to promote confidence and to confirm specific characteristics or parameters considered to be important in the design, construction, operation, and maintenance of a nuclear desalination facility. A number of subjects were identified for more thorough examination and evaluation, covering technical, safety, and economic issues. Such specific subjects for investigation include the interaction between nuclear reactors and desalination systems; nuclear safety requirements specific to nuclear desalination systems; and the impact of feedwater preheating on the performance of RO systems.

The question of infrastructure requirements for nuclear desalination plants is recognized as a major issue, especially for Member States with no nuclear power experience. A demonstration project, if implemented in such a country, could be a very effective and practical framework for developing its nuclear infrastructure, in particular a nuclear regulatory structure.

Desalination facilities connected to nuclear power plants in Japan and Kazakstan have been producing desalted water for years. In addition to these experiences in nuclear desalination plants, a significant number of Member States have shown interest in this option. Ongoing or planned national and bilateral projects will contribute to international experience in nuclear desalination. Such projects should be useful for commercial deployment, contributing to solve potable water supply problems in the next century. These include programmes and activities in China, India, the Republic of Korea, Morocco, and the Russian Federation. These projects, as well as studies and research and development in some other interested Member States, can contribute to a universal demonstration programme. They can be considered as a basis for international co-operation and support, beneficial also for other interested countries. It will be important to utilize the experience gained from these programmes, and not to duplicate activities.

The growing global interest in nuclear desalination led the IAEA to organize an international symposium on "Desalination of Seawater with Nuclear Energy" in Taejon, Republic of Korea, in May 1997. The symposium was convened in co-operation with other international organizations and provided a forum for the review of the latest technological experience, design, and development of nuclear desalination systems and of its future prospects.

Future directions

Studies performed to date show that seawater desalination using nuclear energy is a realistic option for many countries. The continuing expansion of seawater desalination installations presents a potential market for the introduction and commercial deployment of nuclear desalination systems. The IAEA's two-year OIP has identified a few practical technical options for demonstration of nuclear desalination. The demonstration programme has to concentrate on those issues which are relevant to commercial projects. Some issues, in particular technical features which have a major impact on economic competitiveness and on the overall economics of nuclear desalination, do need demonstration to confirm assumptions and estimates. Since several countries have ongoing activities in nuclear desalination, a Co-ordinated Research Programme is being proposed in 1997.

Over the coming years, it will be important to continue and deepen relevant studies and to assist interested Member States in building their nuclear infrastructures, e.g., through implementation of demonstration programmes. The IAEA will continue to support activities that encourage the active participation of countries, and that emphasize the sharing of technical expertise and the effective use of available financial resources. To facilitate the sharing of knowledge and experience, an International Nuclear Desalination Advisory Group (INDAG) is being established with the participation from Member States which are operating, developing, designing, planning, or are interested in nuclear desalination plants.

Results of this international co-operation so far illustrate that practical options exist for the application of nuclear energy to seawater desalination. But to realize them, it will be important to educate the public and to gain the confidence of investors. Means toward this include continued safe and reliable operation of nuclear plants, factual information on the comparative risks and benefits of nuclear and other energy sources, and conservative cost estimates for nuclear desalination facilities. This will be a sound basis for proceeding with effective development, demonstrations, and large-scale applications to help solve the world's growing water supply problem. ❐

Future nuclear energy systems: Generating electricity, burning wastes

Merging the technology of accelerators with reactors holds the promise of producing energy, and incinerating plutonium and radioactive wastes

by Viktor Arkhipov

One of the greatest challenges in the use of nuclear energy is the highly radioactive waste which is generated during power production. It must be dealt with safely and effectively. While technical solutions exist, including deep geological repositories, progress in the disposal of radioactive waste has been influenced, and in many cases delayed, by public perceptions about the safety of the technology. One of the primary reasons for this is the long life of many of the radioisotopes generated from fission, with half-lives on the order of 100,000 to a million years. Problems of perception could be reduced to an essential degree if there were a way to burn or destroy the most toxic long-lived radioactive wastes during the production of energy.

A new technological option, or rather a viable development of earlier ideas, has been introduced recently. It merges accelerator and fission reactor technologies into a single system that has the potential to efficiently generate electricity from nuclear fission and/or transmute the long-lived radioactive wastes. In its simplest form, this accelerator-driven energy production concept uses neutrons produced by a high-energy proton beam to drive a blanket assembly containing fissionable fuel and radioactive wastes. The blanket assembly is like a reactor in that fission is the source of power. Unlike a conventional reactor, however, it is sub-critical and without the accelerator cannot sustain a chain-reaction. The fuel for this system could be uranium, plutonium, or thorium.

Mr. Arkhipov is a consultant in the IAEA Division of Nuclear Power and the Fuel Cycle, Nuclear Power Technology Development Section.

Even as it destroys highly radioactive wastes, the accelerator-driven system would help to meet rising energy needs by producing electricity, the most convenient and versatile form of energy. Demand for all energy sources is going to increase over the next two decades, if only to meet the needs of the world's growing population, which the United Nations estimates will approach 8.5 billion people by the year 2025.

Transmutation of radioactive wastes

Management of radioactive waste in an environmentally safe manner is an important issue being addressed by all countries developing a nuclear industry. In many countries it has become a serious political issue attracting intense critical attention of the general public.

The concept of a closed nuclear fuel cycle was traditionally considered as transmutation (burning) of only plutonium and recycled uranium, with minor actinides (neptunium, americium, curium) destined for final geological disposal. But as time goes on, a new understanding is emerging: reduction of the quantity of actinides would ease requirements for final repositories and make them relatively less expensive.

Neutron transmutation of long-lived radioactive minor actinides by the fission process — which entails producing energy and simultaneously turning them into shorter-lived nuclides — is being intensely analyzed in the technical community. Also being proposed is the neutron transmutation of selected long-lived fission products.

Several possibilities for the transmutation of long-lived nuclides by nuclear reactions have been suggested. In the beginning, the best choice appeared to be the use of nuclear reactors. However, recently there has been renewed interest in what are called accelerator-driven systems (ADS), a technology that seems to show good promise.

Underpinning the interest is the question of what to do with surplus plutonium accumulated in weapons stockpiles, as well as in the much larger and growing inventory of spent fuel from commercial nuclear operations. There is serious political concern over misuse of plutonium and about the release of this highly toxic material into the environment. Many options are being considered to dispose of this plutonium and one is to burn it using the ADS technology. Such an ADS would produce large amounts of electrical energy while simultaneously destroying the plutonium. This appears to offer a better solution to the plutonium problem than multi-millennium storage.

The capability of the accelerator-driven concept can also be applied to simultaneous burn the long-lived fission products and actinides in the waste from existing commercial nuclear power reactors. The goal of burning these fission products is to destroy those long-lived isotopes that, because of their mobility, would be the greatest contributor to radioactive doses from a repository, namely technetium-99, iodine-129, and caesium-135. These three isotopes constitute about 5% by weight of the total fission products generated during power production and are the principal contributors to possible long-term risks associated with geologic disposition. If these three isotopes are destroyed internally, the remaining short-lived and stable fission product waste can be confined in engineered storage, perhaps even at the power production site.

Maximum burn-up of the fission products requires that they be processed on site. By optimizing the accelerator-driven target/blanket assembly for this burning, the volume and half-life of the waste stream can be reduced considerably, thus simplifying long-term storage and secure disposal requirements. Even in this system, where the primary function is to burn radioactive wastes, it is expected that sufficient electrical energy can be produced to pay for the capital and operational costs of the facility.

The goals are laudable, yet it should be kept in mind that the technology still requires substantial research and development. The technical feasibility, and especially the economic and radiological soundness of transmutation, are still to be proved. Consequently, the arguments both for and against partitioning and transmutation of radioactive wastes will have to be carefully compared and evaluated.

Combining energy production and transmutation

The use of accelerators for nuclear energy applications is not a new idea and was proposed as early as the late 1940s by E. Lawrence, inventor of the cyclotron. In the 1950s he promoted the development of a Materials Test Accelerator at Livermore to produce intense neutron fluxes for plutonium production. The Canadian Chalk River Laboratory began intensive studies of accelerator-based systems to breed nuclear fuel for heavy-water reactors. Scientists at Brookhaven National Laboratory also actively promoted accelerator-based options in the late 1970s and early 1980s. For the last five years, scientists at Los Alamos National Laboratory have been reevaluating the accelerator-based technology in the light of today's advances in technology and the world energy perspective.

Most recently, Nobel laureate and past Director-General of European Nuclear Research Centre (CERN), Carlo Rubbia, has proposed and is actively promoting an accelerator-driven energy generation system based on the thorium-uranium cycle.

There are two types of accelerators that could drive this system at approximately 1 GeV and average currents in the range 10 to 100 mA. The first option is to use a linear accelerator. The second is to use a circular accelerator that has the advantage of being a more compact system. Both can achieve the energy required but both require technology development to achieve the needed beam intensities. The cyclotron is limited to currents of 10 to 15 mA due to the difficulty in adequately confining the beam, whereas the linear accelerator is foreseen to be able to deliver perhaps 100 to 200 mA of beam current. Linear accelerators already produce such currents in pulsed mode but to achieve the near-continuous operation for the highest currents a significant engineering development is still needed. A system delivering 15 mA of protons and 800 MeV can drive a blanket assembly to produce 200 MW of electrical power. A circular accelerator is a possible option at this power level. The high-current linear accelerator might drive an energy producing system of 1200 MW electrical. In either case it is expected that about 15% to 20% of the total electrical power be used to drive the accelerator.

Various technical options for transmutation and power production using ADS are now under investigation in several countries and international organizations. A number of ADS schemes are being studied in the frame of the OMEGA Project in Japan (Options Making Extra Gain from Actinides), in the United States (at the Los Alamos and Brookhaven national laboratories), in France (Commissariat à l'énergie atomique, or CEA), in the Russian Federation, at CERN, at the Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development, and at the European Commission (EC).

ADS concepts can be classified according to their physical features and final objectives. The classification is based on the neutron energy spectrum, fuel form (solid, liquid), fuel cycle and coolant/moderator type, and objectives for the system. ADS systems, like reactors, can be designed to work in two different neutron spectrum modes — on fast or on thermal neutrons. There are also attempts at CERN to design a system which will exploit the neutron cross-section resonances in what could be classified as a "resonance neutron" mode. Both fast and thermal systems are considered for solid and liquid fuels. Even quasi-liquid fuel has been proposed based on the particle fuel (pebble bed) concept developed at Brookhaven.

As noted previously, the objective for some ADS is to transmute existing components of spent fuel from nuclear reactors, mainly plutonium and minor actinides, with or without concurrent energy production. Other systems are designed to take advantage of the thorium fuel cycle for energy production. Most concepts are based on linear accelerators. However, the CERN-group and researchers at Brookhaven propose to use a proton cyclotron.

The proposed accelerator-driven energy production system at Los Alamos includes a high-energy proton beam linear accelerator, a heavy-metal target (lead or lead-bismuth), and a liquid fuel system. Liquid fuel is attractive because it avoids the processes of solid fuel fabrication and fuel bundle management while at the same time allows continuous extraction of a significant fraction of fission products during operation. This removal both improves fuel economy and enables destruction of the long-lived component of the fission products. The molten salt option was chosen because it operates at low pressures, has simpler mechanical structures, lower neutron absorption losses, and lower liquid-fuel inventory.

The accelerator-driven subcritical nuclear system proposed by Carlo Rubbia and co-workers at CERN is a fast neutron system. Fuel elements are in solid form, with cladded fuel pins. The nominal fuel is thorium/uranium-233 but it can also run on plutonium (either military or reactor grade) and can fission also the heavier actinides americium and curium. A number of passive safety features of the concept are based on its physical properties.

In Japan during the last two decades, the Japan Atomic Energy Research Institute (JAERI) has been engaged in design studies of transmutation systems. Two types of ADS concepts are being studied: a solid target/core system and a molten-salt target/core system. The concept of an accelerator-boosted molten salt reactor is under study in several universities in Japan. JAERI is about to launch the Neutron Science Project which aims at bringing scientific and technological innovation for the 21st century in the fields of basic science and nuclear technology using neutrons. The study on accelerator-driven transmutation systems and the development of an intense proton accelerator are important parts of this project.

At CEA in France, different laboratories have been working in recent years on several aspects of the technology and on the physics of the ADS. In 1995, it was decided to launch a limited programme, devoted to the experimental validation of the major items related to a generic ADS.

In the Russian Federation, several groups at scientific centres have been working on aspects of the technology and on the physics of ADS systems. Different concepts of ADS with different structures and materials for target and blanket are under consideration. Some studies related to partitioning and transmutation, so-called conversion projects, are financially supported by international institutions, mainly in the framework of the International Science and Technology Center.

The NEA has a comprehensive international work programme related to issues concerning transmutation and separation of fission products and actinides. The NEA Nuclear Development Committee recently set up an expert group to perform system studies on actinide and fission product partitioning and transmutation. The NEA Nuclear Science Committee has a number of co-operative projects covering the scientific and physics aspects of different transmutation concepts.

The EC co-ordinates projects of Member States on a cost-sharing basis and performs studies on minor actinides, fuels, and partitioning at the European Institute of Transuranium Elements. The Institute has been engaged in such research for 30 years. Studies on fuels containing minor actinides have led to a series of irradiation experiments, some of which are already completed. Through another programme, the EC is focusing on the impact of accelerator-based technologies on nuclear fission safety. An objective is to co-ordinate efforts to create the European scientific and technological basis for co-operative projects.

Role of IAEA activities in the field

At the IAEA, activities in this field are being undertaken within the framework of a programme on emerging nuclear energy systems for energy generation and transmutation. The objective is to provide a global forum for the technical review and discussion of programmes, projects, and topics in the development and introduction of nuclear energy, including ADS. The activities focus on the compilation and dissemination of status reports and technical information, and on the support of co-ordinated research. They include the following:

Preparation and publication of a status report on ADS. This work is an outcome of technical discussions at a Special Scientific Programme on "Use of High Energy Accelerators for Transmutation of Actinides and Power Production", held in Vienna, in 1994 in conjunction with the IAEA General Conference. The report is targeted at planners, decision makers, and other parties that have an interest in the development of ADS, and provides an overview of ongoing development activities, different concepts being developed and their project status, as well as typical development trends, and evaluations of the potential of this system for power production, plutonium burning and transmutation of radioactive wastes. It includes contributions by experts from six countries and two international organizations as well as executive summaries of many different areas of ADS technology.

Status report on the thorium-based fuel cycle. This report will update information that has become available over the past six years, and indicate areas which need further investigations. It will include contributions from particular countries and technical groups and feature details of their concepts.

Co-ordinated research programme. This programme focuses on the use of the thorium-based fuel cycle in ADS to incinerate plutonium and to reduce long-term waste toxicities. The first stage covers ADS benchmarks and neutronic calculations, and one objective is to achieve a consensus on the calculational methods and associated nuclear data.

Technical committee meeting on feasibility and motivation for hybrid concepts for nuclear energy generation and transmutation. In September 1997, technical experts will be brought together to review and discuss the advantages and disadvantages of hybrid concepts relative to the current status and potential future direction of nuclear power worldwide, and provide options and recommendations for the IAEA's Member States in this area.

Challenges and opportunities

Many technical and engineering questions remain to be explored and answered before the potential of the ADS concept can be demonstrated. The work ahead will require greater international co-operation to pool expertise and resources.

In many respects, accelerator-driven systems are worth pursuing. By producing electricity, they can contribute to the world's growing energy needs, and by incinerating plutonium and highly radioactive wastes, they can contribute to the goals of environmental protection and safe waste management. Some types of ADS being developed can produce energy from the abundant element thorium in a safe, sub-critical blanket assembly with a minimal nuclear waste stream. Beyond this, there is the promise of systems with the goal to burn weapons plutonium and to incinerate spent nuclear fuel, including its major fission products, from commercial nuclear power plants.

Presently a number of national and regional scientific institutes and laboratories around the world are engaged in research and development of accelerator-driven systems. At the global level, the IAEA's programmes in this field are helping to promote the exchange of information and co-operative research on specific topics. The work is indicative of the heightened interest in ADS technology as a practical tool for contributing to international energy and environmental goals. ❐

Greenhouse gases and the nuclear fuel cycle: What emissions?

Studies show that nuclear energy, compared to other sources of electricity, releases little carbon dioxide or methane to our environment

by Martin Taylor

When concern about the greenhouse effect began to increase in the late 1980s, the topic soon became an increasingly important factor in public debate about the relative merits of different sources of electricity. The case of nuclear power seemed clear cut — it did not emit any greenhouses gases (GHGs) — in contrast with fossil fuels. Of course, it was appreciated that some of the energy used in nuclear fuel cycle facilities was itself from fossil fuels, but it seemed self-evident that this resulted in insignificant quantities of GHGs. However, some nuclear industry opponents began to put forward the view that carbon dioxide (CO_2) emissions attributable to stages in the nuclear fuel cycle were significant, and could even be comparable in magnitude to those from fossil fuel burning. Although this appeared to be an insupportable hypothesis, it was adopted and repeated by other anti-nuclear groups in several countries.

Thus, although the contention that nuclear power indirectly produces significant quantities of CO_2 seemed clearly false, the Uranium Institute (UI) decided to examine these claims and to attempt to refute them in more detail. What follows is a summary of our findings as a result of that investigation.

The nuclear fuel cycle and CO_2

The most widely quoted paper putting forward the view that nuclear power indirectly (through its fuel cycle) emitted significant quantities of CO_2 was presented by Friends of the Earth at the UK public inquiry into the construction of the proposed Hinkley Point pressurized-water reactor; it was written by Dr. Nigel Mortimer. Several other sources used this paper as a reference to support their assertions that nuclear could indirectly produce a large amount of CO_2. The argument rests on the assumption that if the use of nuclear energy were to increase significantly then known uranium resources would be quickly consumed. This would lead to the use of lower grade uranium ores resulting in increased CO_2 emissions, because uranium extraction from lower ore grades would need more fossil energy. Mortimer contends that the CO_2 emissions could reach the same order as those from a coal power station within a few decades.

There are a number of flaws in this argument, and a detailed rebuttal was prepared by Donaldson and Betteridge of AEA Technology. In particular, Mortimer assumes that no further low-cost reserves of uranium remain be found, whereas in fact a revival of nuclear construction and an upturn in uranium demand would lead to increased exploration and the definition of additional resources. In addition, any major expansion of nuclear power (as postulated by Mortimer) would involve within a few decades the increased use of recycling and the commercialization of fast reactors. In any case, even if we assume a modest growth in nuclear output after 2000, then we can calculate that relatively low-cost resources (which are of reasonably high ore grade) already identified today would be sufficient until after 2020.

In 1992 worldwide nuclear generation was about 323 gigawatts-electric (GWe), which required about 55 000 tonnes of uranium (tU). The UI expects that by 2000 annual nuclear generation will total 360 GWe, requiring about 64 000 tU/year. If we assume, for example, that nuclear capacity will increase by 20 GWe per year between 2001 and 2010, and by 30 GWe per year between 2011 and 2020, then total nuclear generation will be 560 GWe by 2010 and 860 GWe by 2020. If the uranium require-

Mr. Taylor is with the Uranium Institute, 12th Floor, Bowater House, 114 Knightsbridge, London, SW1X 7LJ. This article is based on a report contained in the IAEA Technical Document "Comparison of Energy Sources in Terms of their Full Energy Chain Emission Factors of Greenhouse Gases" (IAEA-TECDOC 892) issued in July 1996. References are available from the author.

ment is 160 tU per GWe per year, then the cumulative total of uranium demand would be about 670 000 tU by 2010 and nearly 2.5 million tU by 2020.

By comparison, a UI appraisal of world uranium resources estimates that the total of already known low-cost uranium resources is over 3 million tU. Of this total, over 2 million tU are "Western World" resources, and over 1 million tU are in the former Soviet Union, Central and Eastern Europe, and China.

Thus the hypothesis that nuclear would contribute significantly to CO_2 emissions can be seen to rely on a highly unlikely scenario. There would have to be a massive programme of new nuclear construction, which would quickly use up known uranium resources, and which would continue even in the absence of significant discoveries of additional economic uranium resources. There would be no significant recycling or use of fast reactors, even after several decades.

Comparisons with other energy sources

The UI then looked at what few studies had been done to assess the actual level of CO_2 emissions from the nuclear fuel cycle and to compare this with fossil fuel generation. Two studies, one from Germany and one from the USA, appeared to correctly indicate the magnitude of these emissions.

A detailed study by Weis, Kienle and Hortmann of the German utility association VDEW estimated CO_2 emissions from the nuclear fuel cycle in the former West Germany. They calculated how much energy is used in each of the stages of the fuel cycle, looked at the actual sources of the energy used (i.e. coal, nuclear, hydro, etc.), and then calculated the resulting CO_2 emissions. They also highlighted the fact that energy consumption in the fuel cycle has fallen dramatically in recent years as efficiency has improved. The study concluded that the energy used in preparing fuel for German reactors is 0.7% of the electrical energy which the fuel will produce in the reactor. By far the largest part of this energy use arises from the electricity used in enrichment plants, with only a small proportion from uranium mining. The CO_2 emissions from this energy use, given the actual sources used by German utilities, were about 0.5% of those from a coal-fired station of the same capacity. (*See table*).

Carbon dioxide emissions attributable to various stages of the nuclear fuel cycle, from the German programme

Nuclear fuel cycle process	Specific energy consumed (kWh/kg Unat)	Energy consumed as % of electric energy content	Specific CO_2 emissions from energy consumed (kg CO_2/kg Unat)	Annual CO_2 emissions to fuel a typical 1300-MWe LWR (tonnes)
Mining and milling	59	0.1	47	9 100
Conversion	7	0.01	<7	<1 400
Enrichment	310	0.6	140	27 200
Fuel fabrication	7	0.01	3	600
Total	383	0.7	197	38 300

Source: "Kernenergie und CO_2: Energie-aufwand und CO_2-Emissionen bei der Brennstoffgewinnung", *Elektrizitätswirtschaft Jg 89* (1990).

The study also noted that there will be a reduction in the CO_2 emissions from nuclear in the future (in the German case), due to greater use of gas centrifuge enrichment instead of diffusion, and to the opening of mines with higher uranium concentrations (for example, in Canada). However, it is pointed out that, as the contribution of uranium mining and milling to total nuclear fuel cycle energy use is only about 15%, even if this component changed significantly the effect on the total would be small.

A further analysis was carried out by Science Concepts for the US Council for Energy Awareness (now the Nuclear Energy Institute). This calculated the CO_2 emissions attributable to nuclear plants in the USA, on the assumption that the only significant contribution was from energy used in enrichment (other fuel cycle steps were not considered). It was assumed that the total US nuclear capacity of about 100 GWe requires some 12 million SWU per year, and that each SWU requires 2500 kWh of electricity (using the gas diffusion process). Thus the total electricity required annually for enrichment was around 30 billion kWh. In the region where uranium is enriched, 65% of electricity is generated by coal, 6% by natural gas, and 29% by nuclear and hydro. Thus, the study concluded that nuclear generation produces emissions at a rate of about 4% of the equivalent coal generation.

The principal reason for the difference in the German and US figures is that, while US enrichment is virtually all gas diffusion, only 17% of German enrichment is in diffusion plants. The lower energy consumption of centrifuges accounts for the lower CO_2 emissions. The introduction of laser enrichment technology, now under development, will result in still lower energy use than with centrifuges.

Methane emissions and uranium mining

The UI also examined possible methane emissions from uranium mining. Again, although it seemed self-evident that these were insignificant compared to those from fossil fuels, it was decided to examine the available evidence.

In general, methane is formed from the decomposition of organic material. When such material is trapped beneath the Earth's surface, the methane itself often becomes trapped underground in small gaps in the rocks. Mining in such areas allows the methane to escape, and if it is not collected it seeps into the atmosphere. Underground coal seams inevitably contain significant amounts of methane. In some cases it is possible to collect this from the mine and burn it as a fuel; however, in other mines the ventilation system expels it to the atmosphere. Methane can also be released from other types of mining in rock associated with organic material. Potentially therefore, some methane could be emitted as a result of uranium mining in certain areas. However, such emissions are very rare and consequently few studies have been carried out. The information on which this report is based relates to Australia, Canada and the United States, which account for about 40% of world uranium production.

In Australia and Canada, although underground mines are routinely monitored for explosive gases (including methane), it appears that none have been detected in any uranium mines. The underground uranium mines in these countries are situated in very old rock formations which contain virtually no organic material. In the United States, information is available on one underground uranium mine in which methane was detected. This mine, which closed in September 1988, appears to be the only recent example of a methane producing uranium mine in the USA. The mine in which methane was detected was the Lisbon Mine in La Sal, Utah, operated by Rio Algom Corporation. The mine was classified as "gassy" by the US Department of Labor Mine Safety and Health Administration (MSHA) in 1973 following an ignition incident and the subsequent detection of methane. Further incidents involving outbursts of methane occurred in 1979. In an investigation of conditions in the mine conducted in December 1978, the MSHA reported that the total volume of methane being liberated was 91 920 ft^3/day (2600 m^3/day). A paper by MSHA staff on methane occurrence provides estimates of the rate of methane emission per ton of ore mined. For the Lisbon Mine, this is estimated to be about 100 ft^3/ton (3 m^3/tonne).

The UI was unable to find any other reports of any further uranium mines in any country which have had similar problems with methane. Neither were we able to discover any other references to methane emissions from uranium mining in published sources. Of course, this does not rule out the possibility that there have been additional instances of methane production, but it seems likely that any such instances have been very few in number.

It should be pointed out in this context that little historical information is available about uranium mining in the former Soviet Union, and in some other countries. Therefore it is unlikely that the UI would be aware of any methane emissions from uranium mining there.

Potential methane emissions. The above information relates only to actual uranium mines (both shut down and operating), and not to the potential methane emissions from uranium deposits which have not yet been exploited. Uranium deposits do exist in a wide range of different geological formations, including carbon-bearing rocks, but often not in economically recoverable concentrations. In the past, studies have been performed on the viability of extracting uranium from low-grade coal. In fact, during the period 1963-67 several small US mines in the Williston Basin area of North and South Dakota and Montana produced uranium from ore associated with lignite, which may have contained methane. However, such deposits do not form a significant part of total uranium reserves, and in any case are unlikely to be economic in the foreseeable future.

In perspective

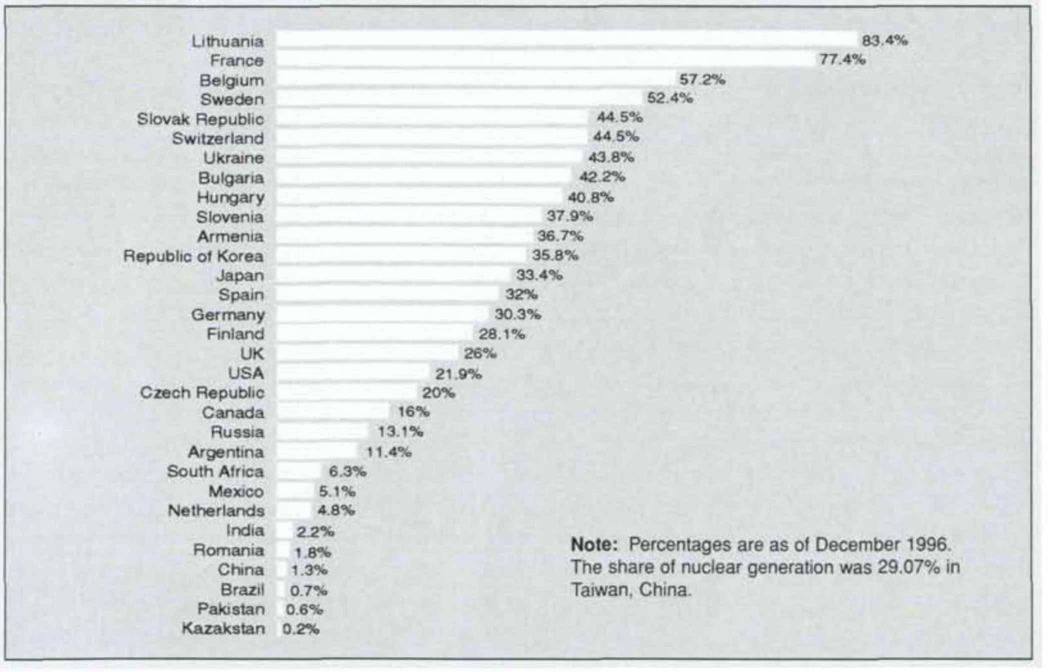
Studies of CO_2 emissions from the nuclear fuel cycle under different circumstances prevailing in two different countries show that they are in the region of 0.5-4% of those from the equivalent coal-fired generating capacity. Assertions that nuclear power could indirectly produce significant quantities of CO_2 depend on a highly improbable scenario. Regarding methane, the information indicates that most uranium is produced with little or no associated methane. In isolated instances, methane may be associated with uranium mining and uranium-bearing ores. But considering that world uranium production involves annual extraction of less than 10 million tonnes of ore, compared with annual coal production of some 4500 million tonnes, it would seem that methane production from uranium mining can be accurately described as negligible. ❒

Nuclear power status around the world

	In operation		Under construction	
	No. of units	Total net MWe	No. of units	Total net MWe
Argentina	2	935	1	692
Armenia	1	376		
Belgium	7	5 712		
Brazil	1	626	1	1 245
Bulgaria	6	3 538		
Canada	21	14 902		
China	3	2 167	1	
Czech Republic	4	1 648	2	1 824
Finland	4	2 355		
France	57	59 948	3	4 355
Germany	20	22 282		
Hungary	4	1 729		
India	10	1 695	4	808
Iran			2	2 146
Japan	53	42 335	2	2 111
Kazakstan	1	70		
Korea, Rep. of	12	9 770	4	3 220
Lithuania	2	2 370		
Mexico	2	1 308		
Netherlands	2	504		
Pakistan	1	125	1	300
Romania	1	650	1	650
Russian Federation	29	19 843	4	3 375
South Africa	2	1 842		
Slovak Republic	4	1 632	4	1 552
Slovenia	1	632		
Spain	9	7 207		
Sweden	12	10 040		
Switzerland	5	3 078		
United Kingdom	35	12 928		
Ukraine	16	13 765	5	4 750
United States	110	100 579		
World Total*	443	351 475	35	27 028

*This total includes Taiwan, China where six reactors totalling 4884 MWe are in operation. Status as of May 1997. Data in the table and graph below are preliminary based on reports to the IAEA, and subject to change.

Nuclear share of electricity generation



Note: Percentages are as of December 1996. The share of nuclear generation was 29.07% in Taiwan, China.

In major step, IAEA Board approves new safeguards measures

At meetings held on 15-16 May in Vienna, the IAEA's 35-member Board of Governors approved new strengthened measures for use by Agency inspectors who verify States' compliance with their commitments not to produce nuclear weapons. More than 180 countries have already made commitments under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and similar treaties. The new measures are detailed in an agreed Protocol through which countries would accept stronger, more intrusive verification on their territory.

Commenting on the Board's action at a press briefing 16 May, its Chairman, Ambassador Peter Walker of Canada, said: "This is a major achievement, crowning five years of effort by IAEA Member States and the Secretariat."

Non-proliferation treaties require that States declare all of their nuclear activities to the IAEA. The key objective of the new measures is to enhance the IAEA's capability to detect possible clandestine nuclear activities in non-nuclear-weapon States and thus to increase confidence that these States are abiding by their obligations. However, while the Protocol is part of a plan for strengthened and more efficient safeguards in non-nuclear-weapon States, it also contains measures that could improve safeguards in other States, including nuclear-weapon States.

The new measures provide enhanced access for inspectors — access to more information about States' nuclear programmes, current and planned, and access to more locations on their territory. Inspectors will have access not only to nuclear sites but also to other locations that could contribute to a nuclear programme, such as research or manufacturing facilities. The new measures include the use of state-of-the-art technologies to trace nuclear activity through samples taken from the environment and to remotely operate surveillance and monitoring systems at key locations in the inspected State. States accepting the Protocol will also be required to simplify the designation of inspectors and visa requirements for them, thus facilitating inspections at sites on short notice. Many of the new measures have undergone extensive field trials in cooperating Member States and build on reinforcing steps already implemented under the IAEA's existing legal authority. The IAEA also anticipates that the implementation of these new measures will lead to more cost-effective use of its safeguards resources.

Welcoming the Board's action, IAEA Director General Hans Blix said in Vienna: "With this decision, an important new chapter in the history of safeguards will begin. The Secretariat stands ready to move ahead with implementation as soon as individual States subscribe." He noted that the Board's action culminated an extensive safeguards development effort that proceeded in two parts over the past several years. Part 1, which the Board approved in June 1995 and now is being implemented, focused on strengthening measures under the Agency's existing legal authority.

United States Press Briefing. At a press briefing in Vienna 16 May, US Ambassador John B. Ritch III said that the United States intends to apply the Protocol's provisions in their entirety, except where they involve information or locations of direct national security significance. One of the five declared nuclear-weapon States, the United States has a "voluntary offer" safeguards agreement with the IAEA under which more than 200 civilian nuclear facilities are open to IAEA inspection. In a statement issued in Washington, DC, on 16 May, US President Clinton commended the IAEA and its Member States for approving the new safeguards measures, and said he would seek legislation that may be needed to implement the Protocol in the United States. He urged "all nations to adopt as soon as possible appropriate protocols to their own safeguards agreements or to make other legally binding arrangements that will put the new system of safeguards in place."

Conferences on nuclear liability, waste safety in early September

Two Diplomatic Conferences have been scheduled by the IAEA for early September 1997. The Conferences are being convened for States to adopt the final texts of legal documents that have been negotiated on the respective subjects of nuclear liability and waste safety.

Nuclear Liability. The Diplomatic Conference on Liability for Nuclear Damage is scheduled 8-12 September in Vienna. Under auspices of the IAEA, States have negotiated two legal instruments that together revise the international regime for nuclear liability — a draft protocol to amend the 1963 Vienna

Convention and a Convention on Supplementary Funding.

Safety of Spent Fuel and Radioactive Waste Management. The Diplomatic Conference on the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management is scheduled 1-5 September. The Joint Convention covers applications in the civilian sector, including spent fuel held at reprocessing facilities as part of a reprocessing activity. With an aim to achieve and maintain a high level of safety worldwide, the Joint Convention obliges States to take appropriate steps for ensuring the safe and environmentally sound management of radioactive waste and spent fuel, and for preventing accidents with radiological consequences. Contracting Parties are required to submit national reports to periodic review meetings on the measures they have taken to implement their obligations under the Convention.

Also before the Board in June were recommendations from its Administrative and Budgetary Committee and items on the implementation of safeguards; technical co-operation activities; the appointment of the Agency's Director General; and the 41st regular session of the IAEA General Conference, which opens in Vienna on 29 September.

Dr. Mohamed M. ElBaradei

The 35-member IAEA Board of Governors in June selected Dr. Mohamed M. ElBaradei, who holds the rank of Ambassador in Egypt's Foreign Service, as the candidate to succeed Dr. Hans Blix as the Agency's Director General. The Board's recommended appointment of Dr. ElBaradei now goes to the IAEA General Conference, which meets in Vienna starting 29 September and will be asked to approve the appointment. The appointment would take effect in December, upon the expiration of the present four-year term of Dr. Blix, who is returning to international service in Sweden. Dr. Blix was first appointed IAEA Director General in 1981 and served four consecutive terms.

Dr. ElBaradei is presently the IAEA's Assistant Director General for External Relations. He has held a number of high-level positions at the Agency since 1984 and has extensive professional and international service in and outside the United Nations system. His career at the IAEA includes serving as the Agency's Legal Adviser and Director of the Legal Division and Representative of the Director General of the IAEA to the United Nations in New York. He also participated as his country's or the IAEA's representative in a wide range of multilateral activities, including work with the United Nations General Assembly, Security Council, the Committee on Disarmament, the Review Conferences of the Treaty on the Non-Proliferation of Nuclear Weapons, the Agency for the Prohibition of Nuclear Weapons in Latin America, and the Organization of African Unity and UN Group of Experts to draft the African Nuclear-Weapon-Free Zone Treaty.

Statements of IAEA Director General

In separate addresses during May, IAEA Director General Hans Blix drew attention to major challenges related to global security and development, sustainable energy supplies, and the future of nuclear energy.

General Meeting of World Association of Nuclear Operators, Prague. Dr. Blix called for collaborative efforts to further improve the safety and performance of nuclear power plants and to broaden awareness of their environmental benefits. Right now, he said, the world is not on a path of sustainable energy supply. Carbon dioxide emissions are rising, despite the Climate Convention adopted at the Earth Summit in 1992, and predictions are that energy-derived emissions of carbon dioxide could rise by nearly 50% over the next 12 years. While nuclear power will not be the only means of reducing such emissions, he said that it will have to be an "indispensable part" of the response since nuclear plants do not emit carbon dioxide into the air. Countries that rely on nuclear power have realized significant positive environmental benefits, he said, citing experience in France, Sweden, and elsewhere. On a global level, carbon dioxide emissions would be about 9% higher if the world's nuclear plants were to be replaced by comparably sized coal plants, he noted. Dr. Blix also reviewed the considerable progress that has been achieved in expanding the international legal framework in areas of nuclear safety and nuclear waste management. "Today we can say that the issue of nuclear safety has been made truly international and that the strengthening of nuclear and radiation safety is an international collaborative effort," he said.

First Session of the Conference of the States Parties to the Organization on the Prohibition of Chemical Weapons (OPCW), The Hague. Dr. Blix welcomed the coming into force of the Chemical Weapons Convention (CWC) as a further step towards a world gradually being freed from weapons of mass destruction. He noted that the IAEA, until the OPCW's formation, held the distinction of being the only international organization performing on-site verification of arms-control commitments. With the deepening of détente, he said, the world had seen a shift in the 1990s from bilateral to multilateral arms-control regimes, exemplified by the CWC and the Comprehensive Nuclear Test Ban Treaty. He voiced confidence in the OPCW's ability to effectively verify compliance with undertakings of the CWC, and noted that the IAEA's experience in the field of nuclear safeguards, both positive and negative, had been of interest in drafting the Convention and in setting up the OPCW. In reviewing significant developments in the field of nuclear verification, he cited the extensive measures to strengthen the IAEA's safeguards system and possible new verification roles emerging in the aftermath of the Cold War. Looking ahead, Dr. Blix called for greater co-operation among international verification bodies in the interests of increasing effectiveness and efficiency. Whereas some types of verification were very specialized, certain verification techniques and challenges were generic to many of the systems in operation or in prospect. As examples he cited the problem of ambiguous "dual use" equipment; the authority for and organization of on-site inspections; the use of remote monitoring equipment; the management of airborne reconnaissance; and the interpretation of overhead imaging.

Bruno Kreisky Forum, Vienna. In connection with the commemoration of the IAEA's 40th anniversary, Dr. Blix addressed the Kreisky Forum on the challenges of preventing the destructive use of nuclear energy, and of developing its constructive potential. He reviewed the many beneficial uses of nuclear techniques and technologies, as well as steps being taken on matters of safety related to nuclear plant operations and radioactive waste management. With regard to controlling the military atom, he particularly focused on four distinct challenges: achieving further reductions in nuclear arsenals, and verification of the cutbacks; achieving universal adherence to the nuclear test ban; encouraging more States to commit themselves against the nuclear-weapons option; and achieving sufficient control over nuclear materials to prevent any construction of bombs by regimes or terrorists.

Symposium on Desalination of Seawater with Nuclear Energy, Taejon. In opening the symposium in the Republic of Korea, Dr. Blix said he was convinced that nuclear energy will be increasingly used to desalinate water for drinking in the future. Potable water is limited in many parts of the world because of economic development and population growth, coupled with pollution. Governments are therefore seeking mature and economically viable technology for desalinating water. Dr. Blix cited the example of Japan and Kazakstan, where desalination facilities attached to nuclear power plants have been producing desalted water for years. Further national or bilateral projects could lead to a broader commercial use, increasing drinking water supply over the next century.

China Nuclear Corporation Seminar, Beijing. Dr. Blix commended China's plans to increase the use of nuclear power to meet a major share of its energy needs. He noted that China had adopted a policy to reduce dependence on coal from 70% to 50% of electricity generation by the year 2020. For many years, fossil fuels, such as gas and oil, were preferred for producing electricity because of their low costs. However, reserves of these fossil fuels are finite and their environmental, health, and other costs can no longer be ignored. Dr. Blix said that renewable and efficient sources of energy will become increasingly important in the future, and it would be a serious mistake to simply write off the nuclear option for inclusion in future energy mix scenarios. He expressed his personal conviction that if technologically advanced countries increased the nuclear share in their own energy mix, this would reduce the environmental damage caused by an increased use of fossil fuels in less developed regions.

Energy issues on agenda of nuclear fuel cycle symposium in June

Nobody disputes that the world's population will continue to grow substantially in the 21st century, as will its appetite for energy. The question is: how will such energy be supplied? In that context, how might the nuclear component look? Will the necessary fuel be on hand? What shall be done with the plutonium that has either been declared excess to military requirements or comes from spent nuclear fuel? These were among the issues debated by over 150 top experts from governments and industry worldwide at the Symposium on Nuclear Fuel Cycle and Reactor Strategy: Adjusting to New Realities, held at the IAEA in Vienna 3-6 June 1997.

The energy outlook to the year 2050 was the subject of a Key Issue Paper debated on the first day. It contains three different scenarios, since projections for such a timescale are obviously subject to a number of variables. What can be said today is that known reserves of four central energy sources — coal, natural gas, oil and uranium — will still be available but will surely be more expensive, barring the discovery of major new reserves that are economically exploitable. As for the nuclear side, if uranium reserves shrink and uranium becomes more expensive, there are a number ways of ensuring fuel availability for existing and new thermal reactors. They include extracting more of the fissionable uranium-235 from natural uranium by reducing the "tail assay" in the enrichment process, higher burn-up in the reactor, and the use of fuel that is a blend of uranium and recycled plutonium, known as mixed oxide, or MOX. There is also the question of the extent to which fast reactors, that can both burn and produce plutonium, may play a role in the commercial production of energy. This is seen by one of the Key Issue Papers as being conceivable but not before the year 2030. Three countries — France, Japan and Russia — are still exploring this technology.

The symposium also considered the question of plutonium use. In this context both international cooperation concerning the disposition of former weapons material, and the question of the extent to which plutonium may be needed as an energy source in the foreseeable future were discussed. Other problems to be dealt with are the necessary safeguards provisions and the health, safety, and environmental consequences of the possible use of plutonium as an energy source. The Key Issue Papers were prepared with wide international participation. A summary was issued on the final day; it is available over the IAEA's *World Atom* Internet services at http://www.iaea.org. More information also is available from IAEA's Division of Nuclear Power and the Fuel Cycle.

Atoms for animal health and productivity

Developments in biotechnology and related fields are helping the world's veterinarians and researchers solve problems affecting the health and productivity of livestock, especially in developing countries. At a recent symposium jointly sponsored by the IAEA and Food and Agriculture Organization (FAO) of the United Nations — the International Symposium on Diagnosis and Control of Livestock Diseases using Nuclear and Related Techniques — more than 100 scientists from developing and industrialized countries reviewed techniques and strategies for effectively diagnosing and controlling livestock diseases. The techniques include nuclear and related methods applied in studies of livestock production and health.

Convened at IAEA headquarters in Vienna 7-11 April 1997, the symposium featured discussions on topics related to serology, molecular biology, epidemiology, social and economic factors, and information technologies influencing the study and control of animal diseases. Concerning serological aspects, discussions focused on the impact of Enzyme Linked Immunosorbent Assay (ELISA) in general, as well as its specific application for rinderpest, foot-and-mouth disease, brucellosis, and trypanosomosis; the development of tests that can be done at the animal's side; the use of biosensors which provide immediate data on the status of a disease; and the impact of monoclonal antibodies as mono-specific reagents. Regarding molecular biological aspects, scientists examined the latest developments in molecular techniques; the use of polymerase chain reaction technology for diagnosis and molecular epidemiology, which enables absolute identification of disease agents at the genetic level;

and novel vaccines. In the area of epidemiology, the symposium presented an overview of modern ideas on diseases in various populations; examined issues of quality assurance for tests used in obtaining disease information; discussed geographical information systems, which map disease patterns and relevant factors; and explored environmental effects on the distribution of diseases. Concerning social and economic factors, participants discussed the effects of different farming systems on problems related to the management of diseases; reviewed costs-benefit exercises in disease control; and examined the training needs of scientists. In the area of information technologies, the meeting presented an overview of computer and telephonic possibilities for exchanging information, storing and analyzing data, and for training and management purposes.

In discussing the range of benefits from new technologies, participants recognized that the use of new "state-of-the-art" techniques for their own sake was not necessarily beneficial. Rather, careful consideration should be given to the most relevant and feasible use of resources taking into account the stage of a country's development. They further stressed the importance of "problem-oriented" science and research, and of giving strong consideration to both "conventional" and "high-tech" applications when assessing the practical needs of developing countries. Scientists further underscored that there are no substitutes for good veterinary infrastructures and well-trained and motivated staff at the national level for identifying and controlling diseases. Proceedings of the Symposium are being published by the IAEA. More information may be obtained from the Joint FAO/IAEA Division at IAEA headquarters in Vienna.

Understanding climate changes

Changes in the atmosphere are heavily influenced by human activities. Assessments of such changes benefit greatly by examining historical records through isotope measurements in ice cores and sediments, for example. To examine the distinct role that isotopes can play in understanding complex processes affecting climate changes, the IAEA convened the International Symposium on Isotope Techniques in the Study of Past and Current Environmental Changes in the Hydrosphere and the Atmosphere 14-18 April 1997 in Vienna.

In opening the symposium, IAEA Director General Hans Blix expressed concern over the increasing concentration of noxious gases such as SO_2, NO_x and CO_2 from the burning of fossil fuels. He mentioned that nuclear power, while economically feasible and meeting 17% of the world's demand for electricity, is free of the air polluting gases that threaten the global climate. He also underlined that programmes of the IAEA on isotope hydrology are helping countries to assess, more fully understand, and manage their water resources, especially where they are affected by environmental changes.

The symposium brought together 180 scientists representing 46 Member States, the United Nations Educational, Scientific and Cultural Organization (UNESCO), the Food and Agriculture Organization (FAO), the World Meteorological Organization (WMO), the World Climate Research Programme (WCRP), and the International Geosphere-Biosphere Programme (IGBP). In all, 65 scientific papers and 59 posters were presented reflecting scientific efforts towards determining changes in the atmosphere and global ecosystems and to identify anthropogenic influences. Isotopic measurements in natural archives — such as deep ice cores, paleogroundwater, lake deposits or organic matter — are prerequisites for any successful reconstruction of past climates and environmental changes. Only this knowledge leads to a quantitative understanding of what might happen in the near future. Current models, for example, indicate that the global temperature has risen by about 5 degrees Celsius in the last 10,000 years. The information, therefore, enables forecasting the impacts on forest ecosystems, desertification, and water resources, as well as the possible occurrence of floods and droughts. It was also clear from the symposium that isotope methodologies are essential for precise determination of the atmospheric budget of greenhouse gases, especially their sources and sinks, to enable prediction and identification of the impacts of climate change. The proceedings of the symposium are being published by the IAEA. More information may be obtained from the IAEA Isotope Hydrology Section.

In Memoriam: Stephane Drege

16 August 1922 - 2 May 1997

When Stephane Drege passed away on 2 May 1997 at the age of 74 in Malaga, Spain, voices rose in tribute, from Paris to New York, from Geneva to Vienna, and beyond. They included those of his Austrian wife, Monika, and his many friends and colleagues around the world. Stephane was a linguist — fluent in French, English, Spanish, German, Portuguese, and Italian – who served as the translator, reviser, and "editor in residence" of the French edition of the *IAEA Bulletin* for much of the past decade. No one could have done the job better, or more personably. His sensitivity, professional experience, knowledge of scientific terminology, nuclear issues, and global developments lent credence to the motto that a good translator is "an editor's best friend". He found mistakes, pampered egos, corrected misinterpretations, and clarified complex and technical terms and concepts with editors and authors, in the language of their home countries, not only his own.

Stephane was among the language pioneers of the United Nations, starting his international career as a translator at UN headquarters in New York in 1946, shortly after graduating from the University of Paris and serving in the French military in Casablanca. Just over ten years later, he returned to Paris, where he led the *Reader's Digest* French editorial section until accepting a similar position at the Berlitz School in Paris. He joined the IAEA in March 1964, rising to chief reviser of the French Translation Section which he served for fourteen years. His later work included assignments with the United Nations Industrial Development Organization (UNIDO) and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), among other international organizations.

The staffs of the *IAEA Bulletin* in all five of its language editions join all those who knew him in paying tribute to Stephane. His life and work live on, through the translated words of presidents, princes, Nobel prize winners, and Directors General he served through his linguistic talents. We will remember him fondly, for his friendship and love of people, his dedicated and distinguished service, and his rich and lasting "joie de vivre".— *the Editor.*

States set nuclear safety review meeting

States that are parties to the Convention on Nuclear Safety have set the framework for their respective peer reviews of national reports on measures for ensuring the safety of nuclear power plants. Meeting at the IAEA 21-24 April, thirty-four of the Convention's Contracting Parties, including 26 countries that operate nuclear power plants, set 12 April 1999 as the date of the first Review Meeting, with national reports to be submitted not later than 29 September 1998. They further adopted rules of procedure and financial rules for the Review Meeting; guidelines regarding the national reports; and guidelines covering the review process itself. The meeting was chaired by Mr. Lars Högberg, Director General of the Swedish Nuclear Power Inspectorate, with Mr. Young-Soo Eun, Vice President of the Korea Institute of Nuclear Safety, serving as Vice Chairman.

The Nuclear Safety Convention, which entered into force in October 1996, applies to land-based nuclear power plants. It aims to legally commit participating States to maintain a high level of safety by setting international benchmarks to which States would subscribe. The obligations of Parties cover, for instance, plant siting, design, construction, operation, safety assessment and verification, quality assurance, emergency preparedness, and legislative and regulatory aspects. As an incentive instrument, the Nuclear Safety Convention is based on the common interest of States in achieving and sustaining higher levels of safety at nuclear power plants. As of May 1997, 37 States had accepted, ratified, or otherwise approved the Nuclear Safety Convention, and 65 States had signed it.

Namibia: Joins Agency's Anti-Trafficking Programme

Fifty countries now have joined the IAEA's programme in support of global efforts against illicit trafficking in nuclear materials and other radioactive sources. In early April, Namibia became the latest country to join the programme, which includes the development and operation of a reliable database of information on incidents of illicit trafficking. Since October 1996, the IAEA has made available authoritative summary information of confirmed cases to its Member States and certain international organizations working with the Agency in this field. Most of the confirmed cases by far have involved individuals trying to illegally sell radioactive sources used in medicine or industry whose unauthorized use or movement poses a danger to public health. Some other cases have involved samples of weapons-grade material confiscated from individuals.

The IAEA's programme involves a number of components related to prevention, response, training, and the exchange of information. While national governments and authorities carry the main responsibility to combat illicit trafficking, effective action requires close co-operation among States and international organizations such as the IAEA. Over recent years, States have requested the Agency to assist relevant State, regional, and international authorities in various ways. In addition to maintaining the database, the IAEA's activities include assisting countries in the development of national systems of control of nuclear materials and providing technical support related to areas of physical protection. It further involves establishing closer collaboration with organizations on the front line of efforts to combat illicit trafficking, especially law enforcement bodies and customs authorities principally responsible for detection and prevention.

Republic of Korea: Desalting Seawater

Although the world's supply of potable water exceeds demand, the resources are not evenly distributed. Some countries have ample supplies, yet many more face acute shortages every day. Increasingly, countries are looking to the sea as a source of water supply, and in some cases, to nuclear power as a source of energy for desalination plants. Based on the completion of international studies on this subject, the IAEA convened an International Symposium on Desalination of Seawater with Nuclear Energy in Taejon, Republic of Korea, 26 to 30 May 1997.

Over recent years, the IAEA has been receiving requests from its Member States to look into the use of nuclear reactors for seawater desalination. There has been a significant increase in the installation of seawater desalination facilities in past decades worldwide using conventional energy sources. Many regions and countries are expected to expand their seawater desalination capacity. The various incentives which in the past have led to the deployment of nuclear energy for electric power generation are being looked to now also for seawater desalination. They include: economic competitiveness, energy supply diversification, conservation of limited fossil fuel resources, technological development and environmental protection through the elimination of emissions causing acid rain, and climate changes originating from the burning of fossil fuels.

As early as in the 1960s, the IAEA surveyed the feasibility of using nuclear energy for seawater desalination and held an international symposium in 1968. Since then, no international forum has been held for discussion and information exchange on this subject.

In 1989, renewed interest in utilizing nuclear energy for seawater desalination by several IAEA Member States led to a resolution at the IAEA's General Conference, requesting the Secretariat to proceed with studies to assess the technical and economic potential of nuclear power for seawater desalination in the light of recent experience. This interest has been confirmed since then through resolutions on nuclear desalination passed every year by the IAEA General Conference.

Several feasibility studies regarding the use of nuclear energy for seawater desalination have been conducted with the participation and support of interested Member States. In addition to the IAEA's studies, several bilateral and national activities on nuclear desalination are in progress to prove its feasibility and economic value for seawater desalination.

The IAEA's symposium summarized global potable water needs, presented an update on state-of-the-art desalination system technologies, and reported on relevant activities of the IAEA and a number of other international organizations. Regarding national experience in the field, participants specifically reviewed the status of ongoing and planned programmes and research and development activities in nuclear seawater desalination, and provided detailed overviews of the design and safety of nuclear reactors for desalination, the different desalination technologies, and the integration of nuclear reactors with desalination systems. Discussions covered topics related to the operation, maintenance, and environmental impact of desalination facilities, as well as water production costs and prospects for nuclear desalination systems, including the possible market for them and the expectations and requirements of potential users.

Poland: Radiation Technology and Environmental Protection

In Zakopane, Poland, 8-12 September 1997, the IAEA will be convening the International Symposium on Radiation Technology for Conservation of the Environment. Radiation processing uses high-energy ionizing radiation, mainly gammas from cobalt-60 and high-energy electrons from electron accelerators. The radiation power needed for industrial processes is typically between ten and several hundreds of kilowatts. The technology has been in use by industries in many countries for more than 30 years in a wide range of applications.

The beneficial environmental impact and opportunities to apply radiation technology for conservation of the environment have been recognized for decades and have been the subject of extensive research. The Agency has been active in this field for many years contributing to new developments, training, promotion, and transfer of technology. In March 1992, the Agency held an International Symposium in Karlsruhe, Germany on Applications of Isotopes and Radiation in Conservation of the Environment. About 90 participants representing 30 Member States attended. Radiation technology was one of the several subjects discussed at the symposium (other subjects included isotope applications for monitoring of environmental pollution, radiotracer studies and nuclear analytical techniques). Several new developments in radiation processing technology have taken place since then. New radiation sources have become available, and successful demonstrations of cleaning of flue gases have been carried out in some countries culminating in an industrial scale plant. Liquid and solid waste treatments using ionizing radiation are also the subject of active research in many institutions, and environmental applications of radiation chemistry are becoming better understood.

The symposium brings together scientists, technologists, industrialists, and regulatory authorities. A particular objective is to consider potential needs of developing countries in terms of applied research in radiation processing and mechanisms for promotion and transfer of such technology.

Brazil: Nuclear Techniques in Agriculture

In Piracicaba, Brazil 27-31 October 1997, the IAEA and Food and Agriculture Organization (FAO) are jointly sponsoring a regional seminar for Latin America on nuclear techniques for optimizing uses of nutrients and water, and for maximizing plant productivity in environmentally sustainable ways. The Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture has long worked to develop improved technologies for sustainable food security involving nuclear methods. Within this Division, the Soil and Water Management and Crop Nutrition Section has the mandate to increase and sustain soil fertility and crop production through integrated nutrient and water management in cropping/farming systems, with minimum adverse effect on the environment. Isotopes and radiation techniques are used to measure and monitor nutrients and water in the soil/plant system for developing sound soil, water and nutrient management practices and maintaining environmental quality. Nuclear methods help to better understand the processes involved and how they affect the environment. The development of modern instrumentation and appropriate analytical techniques has facilitated the applicability and effectiveness of the nuclear techniques over the past decade. The seminar will provide a forum to review the recent progress in nutrient and water management to maximize plant productivity and to preserve the environment using isotope and other nuclear techniques in the Latin American region. Its objectives are to review current progress made in the use of nuclear techniques for studying various aspects of nutrient and water management and environmental problems associated with crop production and sustainable agriculture; and to provide an opportunity for scientists from within and outside the region to present their recent experiences and future plans in the applications of isotope and radiation techniques for developing integrated soil, water, and nutrient management practices in cropping systems.

Canada: Fuel Conference

In co-operation with the IAEA, the Canadian Nuclear Society and its co-sponsors are convening an international conference on Candu fuel in Toronto 21-25 September 1997. The fuel has had an excellent performance record over the past 30 years, and the meeting will examine opportunities for further improvement and for advancement of future designs. Designers, manufacturers, modellers, researchers, and engineers are expected to participate in a range of technical sessions. Major topics include fuel performance; fuel safety; fuel design and development; fuel code development; fuel manufacturing; fuel management; fuel bundle thermal hydraulics; and spent fuel management. Further information may be obtained from AECL, Fuel Design Branch, 2251 Speakman Drive, Mississauga, Ontario, Canada, L5K 1B2; tel. (905) 823-9040; fax: (905) 822-0567.

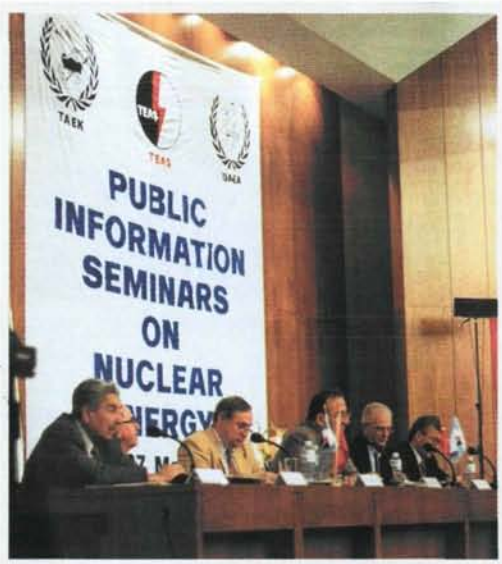
India: Co-operative Research

Hydrologists and other scientists from the Asia and Pacific region recently examined problems concerning groundwater contamination at a seminar at the Bhabha Atomic Research Centre (BARC) in India. It was organized under auspices of the Regional Co-operative Agreement (RCA) for peaceful nuclear development in the region, with support from the Australian Nuclear Science and Technology Organization and the Australian Geological Survey Organization. The main focus was on contaminant migration in deep groundwater, with special reference to the selection of sites for the disposal of high-level radioactive wastes and toxic chemical wastes in deep geological formations.

Turkey: Public Information Seminars

Ways in which nuclear technologies contribute to global energy and environmental goals were highlighted at recent public information seminars in Ankara and Mersin, Turkey. The seminars — convened in late May 1997 — were co-sponsored by the IAEA, the Turkish Atomic Energy Authority, and the Turkish Electricity Authority. They are part of an extrabudgetary IAEA public information programme being funded by Japan. Participating in the seminars were nuclear and energy officials in Turkey, nuclear communicators from the United Kingdom, government officials, invited journalists, and specialists from the IAEA. Topics covered included the energy outlook in Turkey, as well as in Europe; comparative analysis of energy options; nuclear safety and environmental impacts; radiation and human health; waste management; peaceful applications of nuclear energy in medicine and other fields; and nuclear development and the mass media.

Panelists at the Turkey seminar.
(Credit: Lourido/IAEA)



NEW IAEA APPOINTMENTS. Two new appointments have been announced by the IAEA. Mr. Steffen Groth, of Denmark, has been appointed Director of the IAEA's Division of Human Health in the Department of Research and Isotopes, succeeding Mr. Alfredo Cuaron of Mexico. Ms. Denise Loehner, of France, has been appointed Director of the IAEA's Division of Scientific and Technical Information, Department of Nuclear Energy, succeeding Ms. Joyce Amenta of the United States.

EARTH SUMMIT REVISITED. The Special Session of the United Nations General Assembly to Review and Appraise the Implementation of Agenda 21 is opening in New York 23 June. In its contributions, the IAEA is emphasizing the practical environmental benefits that countries are realizing from nuclear applications in fields of agriculture, industry, and science, and the actual and potential role of nuclear power in achieving environmental and development goals.

RADIATION SAFETY. Issues of radiation safety and emergency response are among those featured at an international conference being organized in Brazil later this year. The Brazilian Nuclear Energy Commission (CNEN) is convening the International Conference on the Radiological Accident in Goiânia — Ten Years Later, 26-31 October 1997. The meeting, in which the IAEA is participating, will provide a forum for the exchange of knowledge and experience gained after radiological accidents. Topics include the control of radioactive sources; emergency planning and response; legislative and regulatory frameworks; medical and psychological aspects; and waste management, transport, and disposal. Also planned are technical tours of the accident site in Goiânia and the final waste disposal facility constructed outside the city. More information may be obtained from CNEN, Rua General Severiano, 90 -sala 402, CEP: 22.294-900, Rio de Janeiro, Brazil. The facsimile is +55-21-295-1745.

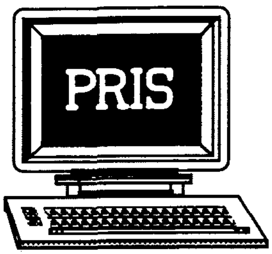
REGIONAL AND INTERNATIONAL APPOINTMENTS. The Paris-based Nuclear Energy Agency of the Organization for Economic Cooperation and Develpment has named a new Director General. He is Mr. Luis Enrique Echavarri of Spain, most recently the Director General of the Spanish Nuclear Industry Forum. He takes up his new duties as of 1 July. In The Hague, the First Session of the Conference to the States Parties to the Chemical Weapons Convention has appointed diplomats to key positions. Ambassador José Maurício Bustani, of Brazil, was appointed as the first Director General of the Organization for the Prohibition of Chemical Weapons, which supervises the Convention's implementation, and Ambassador Prabhakar Menon, of India, was appointed as the first Chairman of the OPCW's 41-member Executive Council, which will oversee the day-to-day functioning of the OPCW. In New York, Australian Ambassador Richard Butler became the new Head of the United Nations Special Commission on Iraq set up by the Security Council following the Gulf war in 1991. He succeeds Swedish Ambassador Rolf Ekeus, who will become his country's ambassador in Washington.

WORLD HEALTH REPORT. People are living longer throughout the world because of global strides in controlling infectious diseases, the World Health Organization reports, but not all the news is good. In its *World Health Report 1997*, WHO warns that non-communicable illnesses — chiefly cancer, heart disease, and diabetes — are posing increasingly heavy health burdens, especially in developing countries. The Report calls for "an intensified and sustained" global campaign to attack main risk factors and to encourage accelerated medical research. More information may be obtained from the WHO, CH-1211, Geneva 27, Switzerland.

ENERGY OUTLOOK. The US Energy Information Administration (EIA) has issued its latest assessment of international energy markets. The *International Energy Outlook 1997* looks at the timeframe to the year 2015 and presents historical energy data from 1970-95. Specific projections of energy use, carbon emissions, and oil production are presented, and prospects for nuclear and other energy sources are discussed. More information may be obtained from EIA's National Energy Information Center, Forrestal Building, Room 1F-048, Washington, DC 20585, USA. *Internet:* http://www.eia.doe.gov.

ON LINE DATABASES

OF THE INTERNATIONAL ATOMIC ENERGY AGENCY



Database name
Power Reactor Information System (PRIS)

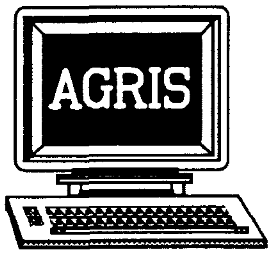
Type of database
Factual

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

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

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

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



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

Type of database
Bibliographic

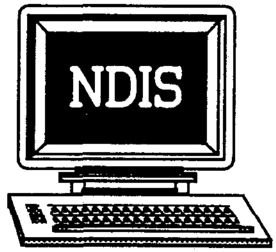
Producer
Food and Agriculture Organization of the United Nations (FAO) in co-operation with 172 national, regional, and international AGRIS centres.

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

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

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

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



Database name
Nuclear Data Information System (NDIS)

Type of database
Numerical and bibliographic

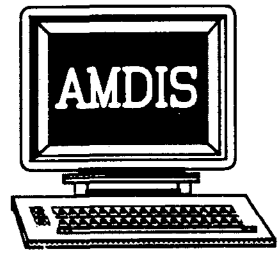
Producer
International Atomic Energy Agency in co-operation with the United States National Nuclear Data Centre at the Brookhaven National Laboratory, the Nuclear Data Bank of the Nuclear Energy Agency, Organisation for Economic Co-operation and Development in Paris, France, and a network of 22 other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

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

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

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

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



Database name
Atomic and Molecular Data Information System (AMDIS)

Type of database
Numerical and bibliographic

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

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

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

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

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

For access to these databases, please contact the producers. Information from these databases also may be purchased from the producer in printed form. INIS and AGRIS additionally are available on CD-ROM. For the full range of IAEA databases, see the Agency's WorldAtom Internet services at http://www.iaea.org.

Database name
International Nuclear Information System (INIS)

Type of database
Bibliographic

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

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

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

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

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

Reports and proceedings

The International Conference on Plasma Physics and Controlled Nuclear Fusion Research, *Proceeding Series, 2640 Austrian schillings, ISBN 92-0-100797-3*

Reviewing the Safety of Existing Nuclear Power Plants, *Proceeding Series, 1920 Austrian schillings, ISBN 92-0-105296-0*

Design and Construction of Nuclear Power Plants to Facilitate Decommissioning, *Technical Report Series No. 382, 440 Austrian schillings, ISBN 92-0-100697-7*

Regulations for the Safe Transport of Radioactive Material - 1996 Edition, *Safety Standards Series No. ST-1/Requirements 680 Austrian schillings, ISBN 92-0-104996-X*

The Use of Plane-Parallel Ionization Chambers in High-Energy Electron and Photon Beams, *Technical Reports Series No. 381, 440 Austrian schillings, ISBN 92-0-104896-3*

Planning and Operation of Low Level Waste Disposal Facilities, *Proceedings Series, 1720 Austrian schillings, ISBN 92-0-104496-8*

Environmental Behaviour of Crop Protection Chemicals, *Proceedings Series, 1520 Austrian schillings, ISBN 92-0-104596-4*

Characterization of Radioactive Waste Forms and Packages, *Technical Reports Series No. 383, 480 Austrian schillings, ISBN 92-0-100497-4*

Reference Books/Statistics

IAEA Yearbook 1996, *500 Austrian schillings, ISBN 92-0-101295-0*

Nuclear Power, Nuclear Fuel Cycle and Waste Management: *Status and Trends 1996. Part C of the IAEA Yearbook 1996, 200 Austrian schillings, ISBN 92-0-102196-8*

Energy, Electricity and Nuclear Power Estimates for the Period up to 2015, *Reference Data Series No. 1, 200 Austrian schillings, ISBN 92-0-102896-2*

The Nuclear Fuel Cycle Information System: *A Directory of Nuclear Fuel Facilities, 1996 Edition, 920 Austrian schillings, ISBN 92-0-101096-6*

Nuclear Research Reactors in the World, *Reference Datea Series No. 3, 200 Austrian schillings, ISBN 92-0-104696-0.*

HOW TO ORDER SALES PUBLICATIONS

IAEA books, reports, and other publications may be purchased from the following sources, or through major local booksellers. Payment may be made in local currency or with UNESCO coupons.

AUSTRALIA
Hunter Publications, 58A Gipps Street,
Collingwood, Victoria 3066

BELGIUM
Jean de Lannoy, 202 Avenue du Roi,
B-1060 Brussels

BRUNEI
Parry's Book Center Sdn. Bhd.,
P.O. Box 10960, 50730
Kuala Lumpur, Malaysia

CHINA
IAEA Publications in Chinese:
China Nuclear Energy Industry
Corporation, Translation Section,
P.O. Box 2103, Beijing

CZECH REPUBLIC
Artia Pegas Press Ltd., Palác Metro,
Narodni tr. 25, P.O. Box 825,
CZ-111 21 Prague I

DENMARK
Munksgaard International Publishers
P.O. Box 2148, DK-1016 Copenhagen K

EGYPT
The Middle East Observer,
41 Sherif Street, Cairo

FRANCE
Office International de Documentation et
Librairie, 48, rue Gay-Lussac,
F-75240 Paris Cedex 05

GERMANY
UNO-Verlag, Vertriebs- und Verlags
GmbH, Dag Hammarskjöld-Haus,
Poppelsdorfer Allee 55, D-53115 Bonn

HUNGARY
Librotrade Ltd., Book Import,
P.O. Box 126, H-1656, Budapest

INDIA
Viva Books Private Limited,
4325/3, Ansari Road, Darya Ganj,
New Delhi-110002

ISRAEL
YOZMOT Literature Ltd.,
P.O. Box 56055, IL-61560, Tel Aviv

ITALY
Libreria Scientifica Dott. Lucio di Biasio
"AEIOU", Via Coronelli 6, I-20146
Milan

JAPAN
Maruzen Company, Ltd.,P.O. Box 5050,
100-31 Tokyo International

MALAYSIA
Parry's Book Center Sdn. Bhd.,
P.O. Box 10960, 50730, Kuala Lumpur

NETHERLANDS
Martinus Nijhoff International,
P.O. Box 269, NL-2501 AX, The Hague
Swets and Zeitlinger b.v.,
P.O. Box 830, NL-2610 SZ Lisse

POLAND
Ars Polona, Foreign Trade Enterprise,
Krakowskie Przedmiescie 7,
PL-00-068 Warsaw

SINGAPORE
Parry's Book Center Pte. Ltd.,
P.O. Box 1165, Singapore 913415

SLOVAKIA
Alfa Press Publishers,
Hurbanovo námestie 3,
SQ-815 89, Bratislava

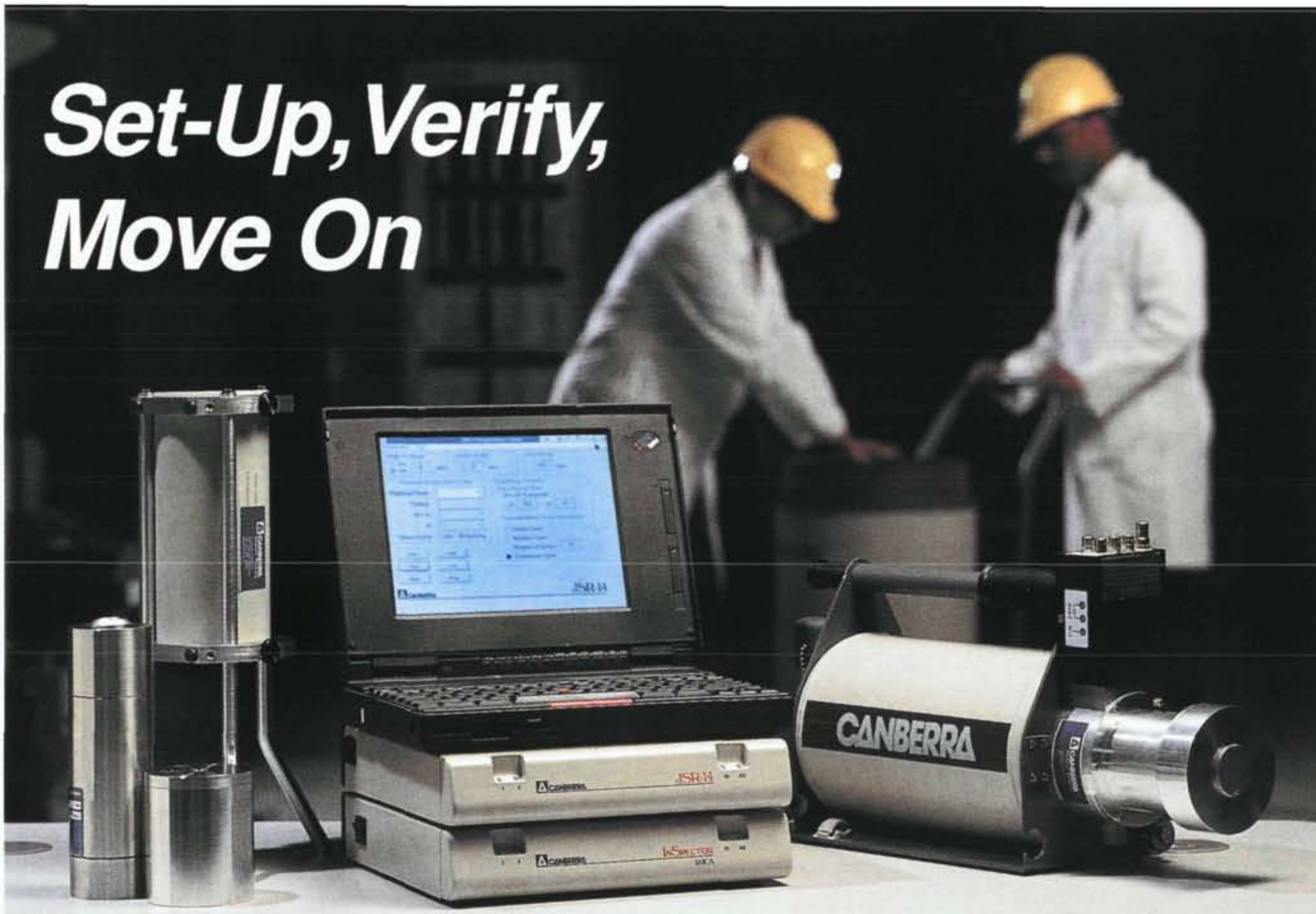
SPAIN
Díaz de Santos, Lagasca 95,
E-28006 Madrid,Díaz de Santos,
Balmes 417, E-08022 Barcelona

SWEDEN
Fritzes Customer Service,
S-106 47 Stockholm

UNITED KINGDOM
The Stationery Office Books,
Publications Centre, 51 Nine Elms Lane,
London SW8 5DR

UNITED STATES AND CANADA
BERNAN ASSOCIATES
4611-F Assembly Drive, Lanham
MD 20706-4391, USA
Electronic Mail: query@bernan.com

Outside the USA and Canada, orders and information requests can also be addressed directly to:
International Atomic Energy Agency
Sales and Promotion Unit
Wagramerstrasse 5, P.O. Box 100
A-1400 Vienna, Austria
Telephone: +43 1 2060 (22529, 22530)
Facsimile: +43 1 2060 29302
Electronic Mail:
SALESPUB@ADPO1.IAEA.OR.AT



Fast Gamma and Neutron Inspection Measurements in a Single System

Safeguards Inspectors make a wide array of verification measurements, involving multiple pieces of equipment. One of the biggest challenges facing the Inspector has been the need to juggle NaI detectors, HpGe detectors, neutron counters, MCAs and shift registers - while still taking the requisite measurements quickly and with minimal interruption to facility operations.

Canberra's safeguards systems simplify and accelerate this operation. Procedures for all NDA measurements - gamma and neutron - are part of an integrated software environment operated from a single host computer. The Inspector simply connects the instrument and selects the measurement procedure. The system does the rest - sets up the hardware, loads calibrations, and counts.

Key front end components - the InSpector Multichannel Analyzer (IMCA) and neutron shift register (JSR-14) - are designed for portability, consistency and speeds operation. 100% computer control and sophisticated battery management facilitate the automated setup and fast portable operation.

The IMCA sets the pace for small size, light weight and lab grade performance. Built in uranium enrichment (enrichment meter and MGAU) and plutonium isotopic (MGA) procedures use predefined NaI, CdTe and HPGe detector setup files.

The JSR-14 combines multiplicity with coincidence counting capabilities together for fast, portable neutron measurements. Special features allow for installed operation as well. The JSR-14 may be configured to operate as a JSR-12 in coincidence mode or as a multiplicity counter using the supplied control and acquisition software that is Windows® compatible and easy to operate. Or operate the JSR-14 using any of the currently available routine neutron counting packages (NCCWIN, Multi, HLNC, etc.) or Canberra's full featured Neutron Assay Software (NAS).

Keep your Inspectors moving with the Canberra IMCA and JSR-14.

CANBERRA Canberra Industries Inc., Nuclear Products Group, 800 Research Parkway, Meriden, CT 06450 U.S.A.
Tel: (203) 238-2351 Toll Free 1-800-243-4422 FAX: (203) 235-1347 http://www.canberra.com

ISO 9001 SYSTEM CERTIFIED

With Offices In: Australia, Austria, Belgium, Canada, Central Europe, Denmark, France, Germany, Italy, Netherlands, Russia, United Kingdom.

POSTS ANNOUNCED BY THE IAEA

NUCLEAR SAFEGUARDS INSPECTOR (97/SGO-4), Division of Operations, Department of Safeguard. This P-4 post participates in the implementation of the Agency's safeguards system and functions as a safeguards inspector. The posts requires a university degree in chemistry, physics, engineering or electronics/instrumentation, or the equivalent, with at least ten years of relevant experience in the nuclear fuel cycle, processing of nuclear materials, material accounting or non-destructive analysis, preferably in plant operation conditions; national or international safeguards experience; demonstrated experience in the use of personal computers; proven supervisory ability. Knowledge of import/export controls, experience in environmental monitoring or in remote data transmission techniques is desirable. *Closing Date: 31 December 1997.*

NUCLEAR SAFEGUARDS INSPECTOR (97/SGO-3), Divisions of Operations, Department of Safeguards. This P-3 post carries out Agency safeguards inspections at various nuclear facilities, and analyses, evaluates and reports on the results of such inspections; analyses and evaluates data collected from various sources including facility records, design information and reports submitted by States, inspection results and computerized databases. This post requires a university degree, or equivalent, with emphasis in a nuclear discipline; at least six years of relevant experience in the nuclear field, preferably in operation of nuclear facilities; demonstrated experience in the use of personal computers. *Closing Date: 31 December 1997.*

SENIOR TRAINING OFFICER (97/025), Section for Safeguards Training, Division of Technical Services, Department of Safeguards. This P-4 post is responsible for the analysis, design, implementation and evaluation of the technical training activities offered by the Section for Safeguards Training. This post requires a university degree or equivalent, in sciences or engineering, with emphasis on a nuclear discipline; at least ten years of combined experience in the nuclear industry of which a minimum of four years must be as an international or national safeguards inspector; the candidate must have demonstrated ability to manage the learning situation effectively in relevant safeguards technical fields and be able to apply basic safeguards philosophy and regulations to various course elements; effective presentation skills is essential. *Closing date: 25 August 1997.*

SAFEGUARDS ANALYST (97/023), System Studies Section, Division of Concepts and Planning, Department of Safeguards. This P-4 post participates in various studies related to the underlying requirements for effective safeguards, criteria for design, operation and evaluation, as well as implementation procedures for facilities; in inter-divisional efforts, Member States' assistance projects and international advisory and consultants' groups to solve safeguards implementation problems. It requires an advanced university degree, or equivalent, in nuclear, chemical or industrial engineering. At least ten years' experience in the nuclear energy field, preferably in safeguards or nuclear material control. *Closing date: 10 August 1997.*

SECTION HEAD (97/026), Latin American Section, Division for Europe, Latin America and West Asia, Department of Technical Co-operation. This P-5 post manages all technical co-operation activities under the Agency's Regular Programme, as well as under the United Nations Development Programme (UNDP) or any other sources of financing, in respect of regional and country projects in the Member States of the Latin America Region. It requires an advanced university degree in science and technology with some knowledge of various peaceful applications of nuclear energy; at least 15 years of managerial and administrative experience at national and/or international level in programming, formulation and implementation of scientific/technical projects. Desirable is an advanced degree in nuclear science and working experience in the field of nuclear science and technology together with experience in the implementation of nuclear technology projects. *Closing date: 25 August 1997.*

RESEARCH SCIENTIST (97/027), Radiometrics Section, IAEA Marine Enviroment Laboratory, Department of Research and Isotopes. This P-3 post carries out research in radiochemistry, nuclear measurement techniques and radiological assessments and participates in the Analytical Quality Control Services (AQCS) programme for radionuclides in the marine environment. Required is an advanced university degree, or equivalent, in a field closely related to radiochemistry, radiometrics, marine chemistry, nuclear physics with six years' post-graduate experience in related subjects. Practical experience in the field of marine radioactivity studies and knowledge in applying raciochemical separations and radiometrics to marine samples; knowledge of radiological and marine transport models is desirable. *Closing date: 15 September 1997.*

UNIT HEAD (07/028), Section OB3, Division of Operations B, Department of Safeguards This P-5 post plans, co-ordinates, and supervises the work of unit inspectors, prepares for, coordinates and carries out extended safeguards inspections; evaluates and reports on the results to provide the Agency with the basis for assuring the international community that the inspected States are complying with safeguards agreement and to further deter non-compliance This post requires a university degree with emphasis on nuclear discipline, at least 15 years of relevant experience in the nuclear industry of which at least 5 years should be in Safeguards areas. *Closing date: 15 September 1997*

READER'S NOTE:

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

POST ANNOUNCEMENTS ON THE INTERNET. The IAEA's vacancy notices for professional positions, as well as sample application forms, are available through a global computerized network that can be accessed directly. Access is through the Internet. They can be accessed through the IAEA's World Atom services on the World Wide Web at the following address: http://www.iaea.or.at/worldatom/vacancies. Also accessible is selected background information about employment at the IAEA and a sample application form. 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, P.O. Box 100, A-1400 Vienna, Austria.


NUCTEC '97
3rd International Trade Fair
Nuclear Technology
and Reactor Safety
December 16–19, 1997
Moscow/Russia
in cooperation with
ENERGOTEC '97
International Trade Fair
Power Generation, Transmission,
Distribution, Alternative
Sources of Energy, Conservation
For further information
please contact:
NOWEA INTERNATIONAL
NOWEA International GmbH
P.O. Box 10 10 06
D–40001 Düsseldorf
Phone + 49 (2 11) 45 60-02
Fax + 49 (2 11) 45 60-740
Germany

Cost-effecti
Solutions –

CONSULTANCY & TECHNICAL SERVICES

SAFETY & REGULATORY MANAGEMENT

ADVANCED DESIGN TECHNIQUES

ADVANCED TECHNOLOGIES

PROJECT MANAGEMENT

CONSTRUCTION MANAGEMENT

PROCUREMENT

TESTING, COMMISSIONING & TRAINING

OPERATIONAL SUPPORT

DECOMMISSIONING

WASTE MANAGEMENT

Meccano is a registered trademark.

The use of isotope techniques in problems associated with geothermal exploitation.

This project addresses the problems associated with geothermal energy development, such as acidic fluids. It aims at further development of isotope geochemical tools integrated with traditional hydrogeochemical methodologies. It involves defining the origins of acidity in geothermal environments, estimating temperatures and detecting various reservoir processes due to exploitation. The genesis of the geothermal fluids particularly acidic in nature can be better understood by isotope techniques.

The application of isotope techniques to the assessment of aquifer systems in major urban areas

This programme addresses the characterization of aquifer systems supplying water to large cities for improved management of groundwater resources. The mismanagement of these resources, due to increasing water supply demand and number of pollution sources, may render the resource unusable. Being a complex environment, the remediation costs of aquifer systems are much higher than those for surface water systems. The CRP will evaluate selected isotope methodologies which provide vital, and in some cases, unique information on the dynamic behaviour of these aquifers.

Evaluation of High Temperature Gas Cooled Reactor (HTGR) performance

The goal of the programme is to start-up steady state and transient operational conditions for the Japanese High Temperature Test Reactor (HTTR) and the Chinese High Temperature Reactor (HTR-10) with support from Member States' test facilities for the major areas of core physics, reactor safety, fission product release and transportation behaviour, thermal hydraulics, reactor dynamics, control and instrumentation, and high temperature component performance. This programme is to be an exchange of technical information between participating countries for the validation of analytical codes and performance models to actual operating conditions, the formulation of research and development code-to-experiment benchmark activities for inclusion in the HTTR and HTR-10 test programmes, and the validation and demonstration of HTGR safety characteristics.

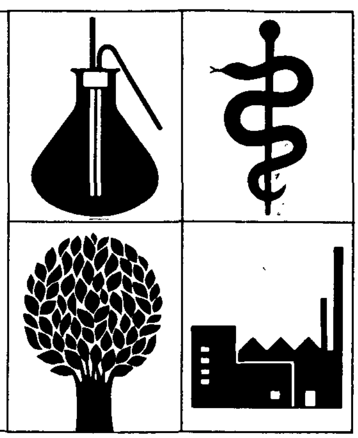
Investigation of methodologies for incident analysis

The main objective of this project is to review operating experience with special emphasis on root cause analysis of unusual events to prevent their recurrence, thus improving plant safety; to identify strengths and limitations of existing methodologies; and to develop a harmonized spectrum of root cause methodologies for particular application areas.

Accident severity during air transport of radioactive material

The goal of this CRP is to build on the existing knowledge of aircraft accidents, and further research issues and collect and analyze information related to aircraft accident frequencies and severities, including their impact, fire, and crush forces.

These are selected listings, subject to change. More complete information about IAEA meetings can be obtained from the IAEA Conference Services 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

SEPTEMBER 1997

Diplomatic Conference on the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management
Vienna, Austria (1-5 September)

Diplomatic Conference on Liability for Nuclear Damage
Vienna, Austria (8-12 September)

Symposium on Radiation Technology in Conservation of the Environment,
Zakopane, Poland
(15-19 September)

IAEA General Conference
Vienna, Austria *(29 September-3 October)*

OCTOBER 1997

Symposium on International Safeguards
Vienna, Austria
(13-17 October)

Regional Seminar on Nuclear Techniques for Optimizing the Use of Nutrients and Water for Maximizing Plant Productivity and Environmental Preservation
Piracicaba, Brazil (27-31 October)

NOVEMBER 1997

International Conference on Physical Protection of Nuclear Materials: Experience in Regulation, Implementation and Operation
Vienna, Austria (10-14 November)

Symposium on Upgrading the Fire Safety of Operating Nuclear Power Plants
Vienna, Austria (17-21 November)

International Conference on Low Doses of Ionizing Radiation: Biological Effects and Regulatory Control
Seville, Spain (17-21 November)

MARCH 1998

International Symposium on Modern Trends in Radiopharmaceuticals for Diagnosis and Therapy
Lisbon, Portugal (30 March-3 April)

MAY 1998

FAO/IAEA International Conference on Integrated Management of Insect Pests through Nuclear and Related Techniques
Penang, Malaysia (29 May-2 June)

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) 2060-21270
Facsimile: (43-1) 20607
E-mail: official.mail@iaea.org

DIRECTOR GENERAL: Dr Hans Blix
DEPUTY DIRECTORS GENERAL:
Mr David Waller, Mr Bruno Pellaud, Mr Victor Mourogov, Mr Sueo Machi, Mr Jihui Qian, Mr Zygmund Domaratzki
DIRECTOR, DIVISION OF PUBLIC INFORMATION:
Mr David Kyd

CHIEF EDITOR: Mr Lothar H. Wedekind
EDITORIAL ASSISTANTS: Ms Ritu Kenn, Mr Rodolfo Quevenco, Ms Juanita Pérez, Ms Brenda Blann
LAYOUT/DESIGN: Ms Hannelore Wilczek
CONTRIBUTORS:
Ms S. Dallalah, Ms L. Diebold, Ms A.B. de Reynaud, Ms R. Spiegelberg
PRODUCTION SUPPORT:
Mr P. Witzig, Mr R. Kelleher, Ms M. Liakhova, Ms M. Swoboda, Mr W. Kreutzer, Mr A. Adler, Mr R. Luttenfeldner, Mr L. Nimetzki

Language Editions

TRANSLATION SUPPORT: Mr S. Datta
FRENCH EDITION: IAEA French Section translation; Ms V. Laugier-Yamashita, copy-editing
SPANISH EDITION: Equipo de Servicios de Traductores e Intérpretes (ESTI), Havana, Cuba, translation; Mr L. Herrero, editing
CHINESE EDITION: China Nuclear Energy Industry Corporation Translation Service, Beijing, translation, printing, distribution.
RUSSIAN EDITION: Produced at the IAEA.

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
Democratic Republic of the Congo
Lebanon
Mali

1962
Liberia
Saudi Arabia

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

1964
Cameroon
Gabon
Kuwait
Nigeria

1965
Costa Rica
Cyprus
Jamaica
Kenya
Madagascar

1966
Jordan
Panama

1967
Sierra Leone
Singapore
Uganda

1968
Liechtenstein

1969
Malaysia
Niger
Zambia

1970
Ireland

1972
Bangladesh

1973
Mongolia

1974
Mauritius

1976
Qatar
United Arab Emirates
United Republic of Tanzania

1977
Nicaragua

1983
Namibia

1984
China

1986
Zimbabwe

1991
Latvia
Lithuania

1992
Croatia
Estonia
Slovenia

1993
Armenia
Czech Republic
Slovakia

1994
Former Yugoslav Republic of Macedonia
Kazakstan
Marshall Islands
Uzbekistan
Yemen

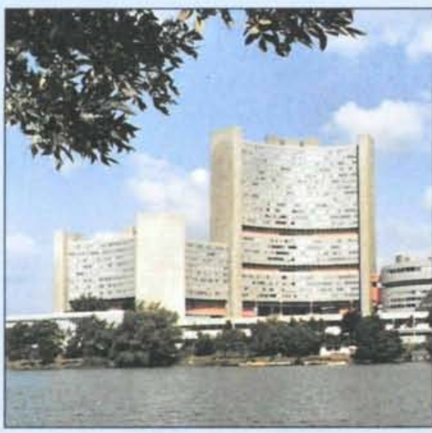
1995
Bosnia and Herzegovina

1996
Georgia
Moldova

Eighteen ratifications were required to bring the IAEA's Statute into force. By 29 July 1957, the States in bold face (including the former Czechoslovakia) 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

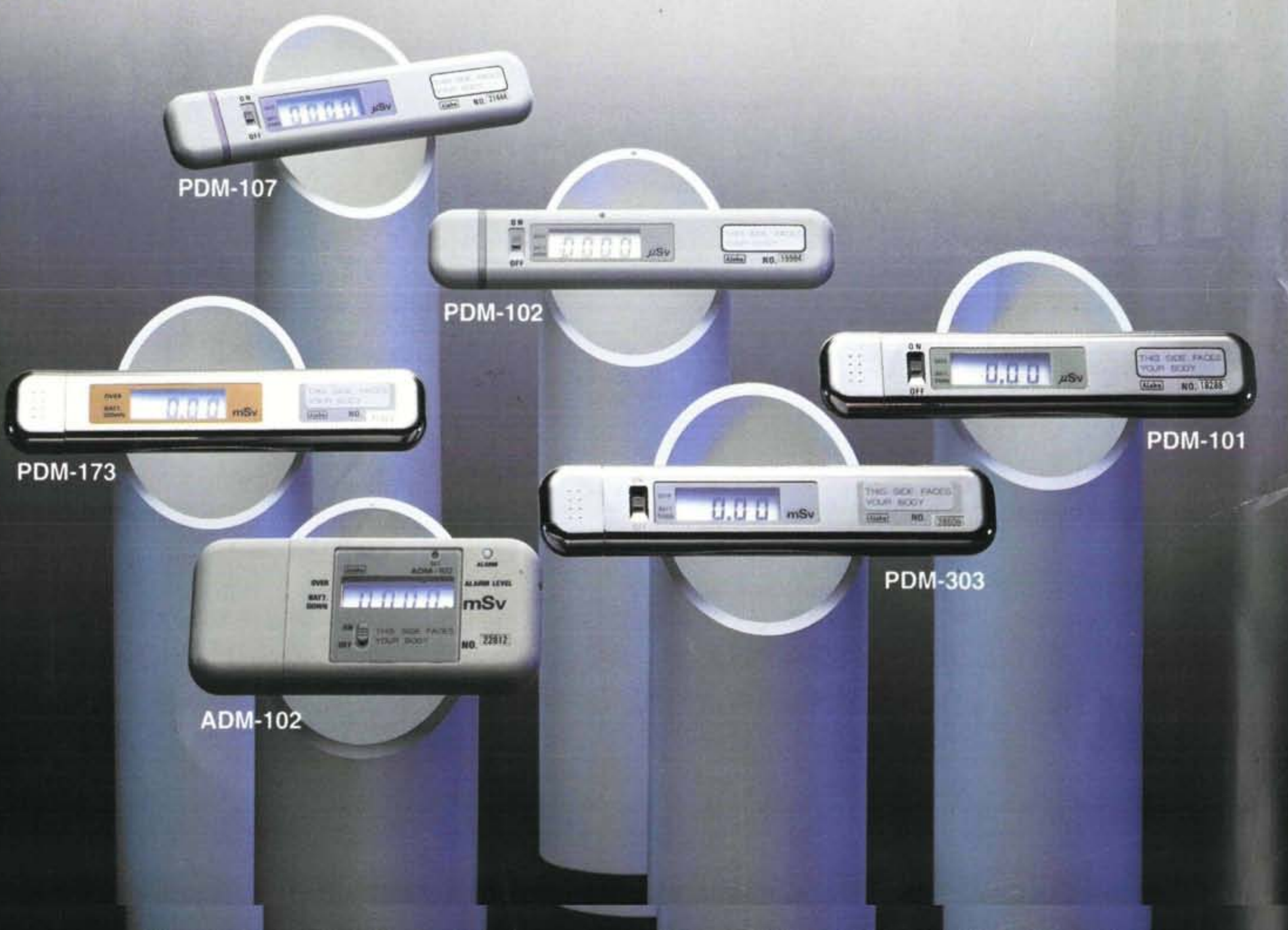
SCIENCE AND HUMANITY

ALOKA

ALOKA CO., LTD.
6-22-1 Mure, Mitaka-shi, Tokyo 181, Japan
Telephone: (0422) 45-5111
Facsimile: (0422) 45-4058
Telex: 02822-344

To: 3rd Export Section
Overseas Marketing Dept.
Attn: N. Odaka

Safety, convenience and a variety of styles to choose from.



INSIDE

TECHNICAL CO-OPERATION

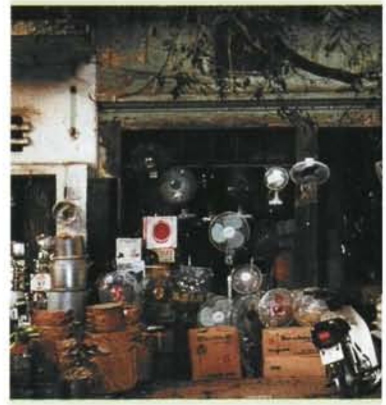
International Atomic Energy Agency

June 1997 Vol. 3, No. 2

CONTENTS

New Tools and Energy Choices

An adequate supply of affordable energy is critical to sustained economic growth; yet many developing countries lack either the natural, financial or technical means to ensure reliable supplies. Moreover, concerns about the impact of power generation on human health and the environment mean that countries must be able to assess and inter-compare all options in planning their energy systems.



Credit: L.Langlois/IAEA

Senior officials are participating in the energy planning programme (ENPEP). Demand for electric power is rising rapidly in Viet Nam. 40% of Viet Nam's population is below the age of 15 years. Credit: L.Langlois/IAEA

A project called DECADES was set up by nine international organizations including IAEA, to develop computerized tools (databases and methodologies) that can help national energy planners meet these challenges. In its first phase (1993-96) DECADES produced three databases and an analytical model called DECPAC, based on models such as ENPEP (for energy and power evaluation programme) jointly developed by the IAEA and the Argonne National Laboratory, USA. Using the personal computer (PC) based information package and the analytical model, national planners can compare energy systems on the basis of power production, as well as emissions of greenhouse gases and other pollutants, and add other elements to the analysis.

One DECADES database on "Reference Technology" covers all available primary energy power

continued on page 6

Technologies to Keep Spent Sources Safe

The analogy of building a brick wall is often used to illustrate what is meant by a nuclear safety infrastructure. In building up the basic foundations for safety in countries with only limited nuclear programmes, some bricks represent required legislation (on waste management and radiation protection), while others are the independent regulatory body with powers to ensure that the laws are obeyed. Still others represent technical capabilities and trained staff to handle all safety-related tasks.

IAEA activities have helped place the bricks in many countries, but some national walls still need strengthening. The focus of two separate but related multi-country IAEA technical co-operation (TC)

continued on page 4

Reactor Safety Top Priority in Former East Bloc

A full-scope simulator is used for training nuclear plant operators at the Balakovo training centre in Russia. Credit: US Department of Energy

Throughout the Cold War years, the nuclear power industry in the Soviet Union was effectively governed by considerations different from those in the West. Reactors were designed and built to respond primarily to requirements for reliability and availability. They were operated to produce efficient power, but regular shutdowns for inspection and maintenance were not required. Conditions then differed very significantly in terms of public participation, design and operation requirements, and notably in safety standards in general. Nuclear authorities today are addressing a number of serious issues.

The IAEA, together with several other international bodies and a number of individual countries, is involved in numerous activities to enhance the safety of reactors from that period. The main objectives are to rectify design shortcomings as much as possible by way of backfits and structural reinforcements, to improve operational efficiency, to strengthen and assist regulatory authorities and to nurture safety culture throughout the nuclear energy sector in the region.

Of the Soviet-designed reactor types, only WWERs (water cooled, water moderated energy reactor) were built outside the former USSR. The earliest types still in operation are WWER 440/230s (design capacity 440 megawatts, model 230). There are 11 of these units in operation in four countries: Armenia (1); Bulgaria (4); Slovakia (2); and four in Russia itself. These were designed before formal nuclear safety standards were issued in the Soviet Union and they lack basic safety features common in pressurized water reactors.

An important part of the IAEA programme addresses the safety of WWER 440/230 reactors. It is important to continue such activities into the foreseeable future because the problems will not disappear tomorrow, nor will their economic dilemmas. These countries are not likely to afford replacement power plants, nuclear or otherwise, for the next 10 years.

International involvement is also important to enhance and maintain safety and efficiency of other Soviet-designed reactors — the more modern WWER 440/213s and 1000s and the RBMKs — in operation. There are 14 WWER 440/213s in operation: Czech Republic (4); Hungary (4); Slovakia (2); Russia (2); and Ukraine (2). There are also 19 WWER 1000s of which only two (in Bulgaria) are outside the ex-USSR, while Russia has seven and 10 are in Ukraine. RBMKs are operating in Lithuania (2), Russia (11) and Ukraine (2 in Chernobyl).

An IAEA-coordinated international expert study, initiated in 1990, analyzed safety-related problems, both generic and plant-specific, in all these reactors and ranked them on the basis of safety significance. The findings have been a useful frame and guide for other Agency activities, including national and regional Technical Co-operation (TC) projects. They have also helped create linkages with a number of international programmes - notably of the European Commission, European Bank for Reconstruction and Development, OECD Nuclear Energy Agency, G-24, and World Association of Nuclear Operators - to upgrade the safety of these plants.

IAEA TC projects, especially those in eastern and central Europe, have focused mostly on enhancing national regulatory capability and improving plant safety. Under the Soviet Union almost all nuclear activities were handled by Russian experts. National regulators elsewhere in the region lacked both information about their plants and independence. Regulatory laws and regulations were inadequate. These countries are now addressing the issue and TC is helping them formulate adequate laws and regulations to give regulators the legal independence and authority they need, as well as to provide training and equipment. Projects to strengthen regulation were recently completed in Romania and Slovakia, and similar ones started in Ukraine and Armenia this year.

The most remarkable activity on the plant safety front led to the formal opening this April of a maintenance training centre at the site of the Paks nuclear plant in Hungary, complete with all the key parts of the core area of a WWER 440/230 reactor (see item on page 7). The full-scale mock-up reactor will help train and re-train plant maintenance staff, in the same way as simulators train operations personnel, not only those of Hungary but of all countries with any model of WWER reactor, bilaterally or through the Agency.

Regional Initiatives to Improve Plant Safety

In Agency efforts to improve the safety of WWERs, TC will continue to pursue country-specific issues through national projects. But an emerging trend is to mount regional programmes addressing broad issues that the IAEA identifies as common to a number of countries. This approach is by nature more proactive, in that it identifies opportunities for interventions rather than waiting for requests from governments.

Regional projects cover a variety of pertinent safety improvement issues of the older and newer WWER reactors. The problems addressed have been given high priority by the countries themselves. One project is to transfer advanced non-destructive testing (NDT) methods, over the next three years, to seven countries that wish to improve in-service-inspection (ISI) procedures. Croatia, has given the Agency free use of a laboratory and training facilities, complete with the required equipment to be used for training activities. The common methodology is a combination of workshops, discussions and hands-on training.

The nuclear power sector in the region is very different from what it was. Modern WWER 440/213s and 1000s are recognized for their high design quality. In older models still in operation, safety issues of the past are receiving priority concerns today. Upgrading programmes have been launched. Training and retraining for maintenance and operational personnel are now normal practices. Plant safety has replaced plant productivity as the driving aspiration. With continuing efforts, the rationale of all IAEA-TC projects, national and regional, is being fulfilled: to ratchet up safety levels without depriving the countries of the energy they need for continuing advancement.

Improving Nuclear Fuel Performance

A technician inspects the structure of a fuel assembly. The integrity of fuel assemblies under various conditions can be modelled using sophisticated computer codes. Credit: Framatome.

Nuclear fuel is made to order for various types of power plants and even for particular models. Good fuel performance is a key factor in cost-effective power production. It is also vital for operational safety, making it important for regulatory authorities to have in-depth knowledge of the design basis, fabrication history and characteristics of the fuel, as well as how it is expected to behave under various operating and accident conditions in the reactor.

Fabricating plants in many countries can customize fuel to particular specifications. Countries of central and eastern Europe which operate USSR-built WWER reactors traditionally bought fuel from Russia (which now sells only for convertible currency), but are now able to get supplies in the global market. However, long dependent on the Soviet Union, these NPP operators lack a comprehensive understanding of the fuel they use.

To help solve this problem an IAEA technical co-operation regional project (1995-96) was initiated to provide training and expertise for Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia and Ukraine, as well as key computer codes to assess fuel performance in various conditions and the database to conduct fuel modelling on their own. As a follow-up, a new two-year (1997-98) TC Model Project for the region aims to transfer knowhow to each of the eight countries plus Turkey — on licensing procedures and using computerized fuel modelling codes (systematic procedures to prepare mathematical models that represent actual circumstances affecting the fuel). The objective is that each national regulatory body will eventually carry out the licensing function independently.

The project targets utilities and regulators, as well as developers who will design and qualify national fuel codes. A project questionnaire is designed to identify the knowledge gaps and specific needs of the different countries at the outset. Training courses and fellowships will then be arranged to cover Agency guidelines on fuel safety, the national regulator's role in fuel licensing, Nuclear Safety Convention requirements, quality assurance of fuel performance and fuel fabrication and safety criteria for utilities and regulators.

Technologies to Keep Spent Sources Safe *(continued from page 1)*

Model Projects, launched this year, is to help consolidate radiation protection and introduce technologies for storing radioactive wastes in a safe manner.

Because radioactive wastes remain active and dangerous for long periods, technology for waste management is an essential part of nuclear infrastructure. It is not good enough to make certain, through regulation, that radioactive sources are handled with due care while they are being used, if they are then carelessly put aside when they are taken out of service and become waste.

Waste management technologies that are transferred to developing countries must match their needs and national technical capabilities. Project target countries typically make little or minimal use of radioisotopes. Most of them use sources only in hospitals and for some industrial work, such as radiography of welds. A few also have nuclear research institutions. Therefore, the project focuses on common sense solutions in five key potential problem areas.

The first urgent need is conditioning and storing spent radium needles. These tiny radium-226 sources were extensively used, mainly to treat cancers, all over the world for some 70 years. But their use has long been discontinued and replaced by more modern sources of ionizing radiation. Given radium's half life of 1600 years, the obsolete sources should be in long term safe storage until final disposal. Instead, the 15,000 or so identified in developing countries are often improperly stored, and some are known to be leaking.

The project is using a relatively simple technology to condition and store this waste. Uruguay is a prime example of a developing country in need of conditioning technology for its outmoded radium sources. All 150 needles and some old medical sources, containing some 2.6 grams of radium in total, had been removed from service and brought to its nuclear research centre (Marie Curie in the long and heroic research which later killed her, extracted only milligrams of radium from pitchblend).

Participants get hands-on training for conditioning of spent sealed sources at the Lo Aguirre Centre for Nuclear Studies in Chile. *Credit: V. Friedrich/IAEA*

The IAEA convened a team of three specially trained Brazilian experts to condition them. Under IAEA supervision the shielded source containers were opened, inventoried, funnelled into stainless steel capsules and the capsules welded. As part of the required quality assurance procedures, the welds were then leak checked. The capsules were placed in specially constructed lead shields which were emplaced for storage in 200 litre drums lined with some 500 kilograms of cement.

So all Uruguay's unwanted radium-226 is now in four safely stored, properly labelled drums, awaiting final disposal in a deep repository for very long half-life wastes, when one is established. Four more countries in the region and another in Europe have now chosen to go the Uruguayan route. Nicaragua, Guatemala and Jamaica are collecting all their needles in a single place, as required by the project. Later this year expert teams will repeat the process there that was done in Montevideo. Chile has begun training its own skilled team under the Interregional Model Project, to do the job itself. The project will also help Croatia become the first country in Europe to secure all its radium sources this autumn.

The second need addressed by the project is to make sure that less urgent sources commonly used in medicine and industry are also safely stored after they cease to be used and are regarded as waste. The isotopes - caesium-137, cobalt-60, iridium-192 and others - are not as long lived as radium. But they are intense and can be lethal. The ideal solution would be: Return to Vendor. A clause requiring the supplier company to take back spent sources may be written into future contracts. Even so, for sources already imported, as well for future imports even under take-back contracts, there may be obstacles to re-export. So the project will provide conditioning technologies similar to that for the radium needles. Eventual disposal in near-surface repositories, of the type existing in many developed countries, is adequate for these isotopes because they will decay away in a relatively short time.

Lax control or civil upheavals such as war can result in sources being abandoned, buried in rubble, and otherwise lost. The new project's third area is to trace lost sources, retrieve them and store them in a safe manner. Tracking down sources outside of regulatory control is technically straight-forward and cost-effective compared with the effects on public health and the costs of clean-up if they are damaged or mishandled. The project's fourth and fifth areas are designed for countries with larger nuclear programmes (those with research reactors or big hospitals) where solid and liquid radioactive wastes are produced regularly. Here the are produced regularly. Here the Model Project has a longer and more complex task: on the one hand to set up centralized processing and storage facilities; on the other to upgrade waste operator capabilities. Operator training is usually provided through expert missions sent to the country and through fellowships and visits to research centres in the region. A special new demonstration programme at selected national centres permits operators to not only see waste processing techniques being applied but experience working with real radioactive waste.

This year the project helped 10 operators from five Latin American countries to get such training at the Centre for Nuclear Studies (CEN) Lo Aguirre in Chile. Turkey's Cekmece Research Centre in Istanbul hosted trainees from four countries in Europe and West Asia. Plans are now underway to arrange hands-on demonstrations for the newly independent states of the former Soviet Union, and for countries in the East Asia and Pacific region. The technological bricklaying has already improved a number of infrastructure walls largely because governments, already aware of the problems, find the tools provided through the Model Project appropriate to their

Radioactive Decay & Half-life

Half-life is the period of time required for radioactive decay to reduce the inventory of a given isotope to half of its initial value. Decay is spontaneous, without any outside stimulus. The decay rate does not vary, so some isotopes with long half lives will be around for millions of years. Half-life is a key parameter in strategies and engineered structures for treatment and safe storage of radioactive wastes. Compared with the 1600-year half-life of radium-226, caesium-137, cobalt-60 and iridium-192 have half lives of 30 years, 5.3 years and 74 days respectively.

Nuclear Power's Contribution

Energy is perhaps the key controlling factor for economic growth and development in the next century. Endless statistics and thoughtful analysis estimate mind boggling energy requirements for the future, but the practical choices for sources of energy come down to a select few — each with its own consequences.

A total of 443 nuclear power plants are currently operating around the world. During 1996, five nuclear power plants representing 5717 megawatts-electric (MWe) net electric capacity were connected to the grid in France, Japan (2), Romania and the United States. In April 1997, Wolsong-2 in the Republic of Korea, a 650-MWe unit, was connected to the grid. During 1996, construction of three new nuclear reactors started — two at Qinshan in China, and one at Onagawa in Japan — bringing the total number of nuclear reactors reported as being under construction to 35 in 14 countries. Several Member States such as Viet Nam are exploring the feasibility of the nuclear power option with the co-operation of the Agency. Viet Nam has concluded that by 2010-2015, a nuclear power plant with a capacity of 800-1000 MWe should be introduced.

Nuclear power will continue to play an important role in the energy mix of many Member States over the next few decades. While most States favor renewable energy sources, the contribution of these sources to global energy demand today is limited to about 2% and likely to remain so for the foreseeable future. With the growing demand for energy and electricity, and the shadow of increasing concern over the greenhouse effect and acid rain, the nuclear power option will remain highly relevant to each State's energy mix — depending on a number of variables: the availability of other energy sources, the existence of adequate industrial and regulatory infrastructure, public acceptance and others.

Credit: Mitsubishi Heavy Industries

Worldwide in 1996, total nuclear generated electricity grew to 2300 terawatt-hours (TWh). This is more than the world's total electricity generation — 1912 TWh — from all sources in 1958. Overall nuclear power plants provided approximately 17% of the world's electricity production in 1996. Cumulative worldwide operating experience from civil nuclear reactors at the end of 1996 was over 8135 years.

All in all, 17 countries and Taiwan, China relied upon nuclear power plants to supply at least a quarter of their total electricity needs.

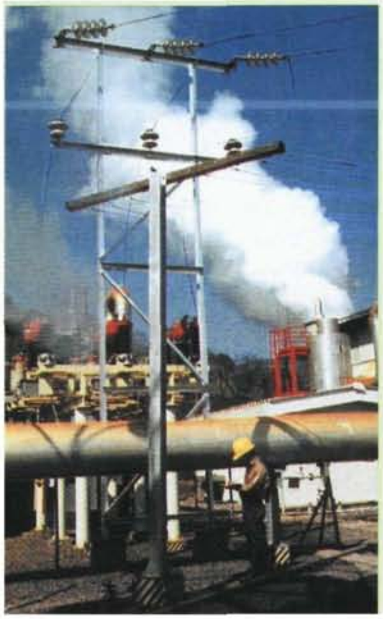
The decision to use nuclear power, conventional fossil fuel generated power, hydro, geothermal, or others, reflects a process of trade-offs. The role of the IAEA is to co-operate with Member States in making informed choices. These areas of co-operation include assessment of energy sources; technical support in areas such as safety, waste management, physical protection; quality assessment and control; energy planning; and training. The IAEA is the only international organization fulfilling this role, and is therefore an important partner for charting our energy future.

generation systems worldwide, and those expected in the next 20-30 years. A second global database, "Environmental and Health Impacts of Energy Systems," presents impact data, not only from power plants but along the whole length of each energy chain. A third provides a generic model for national databases, and can be customized by including country-specific information such as electricity demand in peak load, duration of load, hydrological conditions, committed additions and retirements of power plants, land-use or utilization of local fuels.

DECADES tools were transferred to some 35 countries in Phase-I through training courses involving both lectures and hands-on use. Some 80 trainees were provided with copies of the databases and DECPAC on diskettes, to share the experience with colleagues at home. Two or three trainees from a country participate at the same time; thus they could begin building country-specific studies during training. Most national databases have now been peer-reviewed.

Training in Phase-1 was complemented by a three-year IAEA Coordinated Research Programme (CRP) that focused on national case studies to assess and compare the potential role of nuclear and other energy sources in reducing greenhouse gas emissions and other burdens on the environment. CRPs are designed so that all participants follow the same strict guidelines and present results that are comparable.

Phase-II of the CRP which began this year has two key objectives: to enhance the models and databases, and disseminate them widely. Databases will be extended to cover other pollutants such as heavy metals. Specific impacts of the different emissions - on human health, buildings, crops, and the environment — will be included and in due course quantified, ranked or weighted. Models will be elaborated to forecast future electricity demand in different countries. A CRP also has



Geothermal energy production in El Salvador. Credit: J. Perez-Vargas/IAEA

been established to compare electricity generating strategies in terms of their sustainability over time. Phase-II also is aiming towards examining the entire energy spectrum, as opposed to electricity generation alone.

Training is a vital part for disseminating the new tools, and the current goal is to graduate another 100-200 trainees during this phase. Once they master the methods, energy planners and decision-makers need to begin applying them in formulating real national plans. Brazil and Croatia will be the first two countries to apply the DECADES databases and the DECPAC model in developing their national plans.

Brazil's size combined with the existence of several independent and rival regional electricity utilities make the development of a coherent plan more than a little difficult. Electric power plays a crucial role in the economy of the State of Minas Gerais, which is based on manufacturing industries with heavy energy consumption. The State's energy utility (CEMIG) is already familiar with the ENPEP package, through an IAEA technical co-operation project completed in 1996, and now has considerable capabilities to carry out studies and make decisions for future energy needs. A new TC project, for which funding is still being sought, will enable CEMIG to use the DECADES tools in order to include health and environment factors in assessing electricity generating systems. At the same time the DECADES project will introduce its package to other utilities in the country.

An earlier TC project to help apply Agency power planning methodologies in Croatia has been extended (1997-98) to "enhance national capabilities for ... energy sector planning" as a whole. All relevant players in the country are involved in the activity, from the Ministry of Economic Affairs to university faculties and the power utility, the biggest oil company, national energy institute, and even some non-governmental organizations that promote emerging energies. One essential task is to do a comparative assessment of the different options to produce electricity, using the DECADES package. Two "graduates" of the DECADES approach have prominent roles in the working group that will conduct the study, scheduled for completion within 12 months.

Lithuania's electricity depends mainly on its USSR-built Ignalina nuclear power plant. A new TC project was started this year to help the national energy institute identify practical ways to expand power generation, using other primary sources and even other nuclear plants, as the country moves towards a market oriented economy. The project will introduce, train, and apply the basic IAEA planning methodologies (including ENPEP) on which DECPAC was developed. Elsewhere, in two ongoing TC regional projects, 26 European and nine West Asian countries are taking part in workshops, technical forums and exchanges that provide training in ENPEP, thus laying the groundwork for using the DECADES package to develop environmental and people friendly energy systems in dozens of countries in the 21st century.

In Brief: Updates of Stories and News Events

Training Power Plant Managers

A regional course on management responsibilities in the training and qualification of NPP personnel, organized by the IAEA in co-operation with the German Government, will be held at the Forschungszentrum Karlsruhe, Germany, from 6 to 10 October. The 20-25 participants will be senior line managers of utilities, NPPs or regulatory bodies from IAEA Member States in the Europe region and among the CIS countries. Preference will be given to candidates from developing countries receiving IAEA technical assistance.

The course — held in Russian and English — will brief managers on their roles and responsibilities in training NPP operators. It will also introduce the systematic approach to training (SAT), demonstrate how this is applied at the Neckarwestheim NPP and also cover the establishment of national regulations, policies and procedures. Finally, it will focus on the transfer of experience by both lecturers and participants and contribute to consistency, efficiency and quality assurance in the training, qualification and licensing of NPP personnel.

Progress in TCDC

The IAEA's increasing emphasis on Technical Co-operation among Developing Countries (TCDC) was reiterated in its joint statement with four other specialized agencies of the UN common system at the 10th session of the High Level Committee on TCDC in New York early in May. Through its TC programme, the IAEA has stimulated private sector development, assisted in the transfer of technology and trained personnel at the national and the local level.

The IAEA encourages technical co-operation between its developing Member States mainly through three regional agreements for co-operation in research, development and training in nuclear science and technology. These agreements — in Africa, Asia and Latin America - aim to expand regional responsibility for programmes financed by the IAEA, other donors and the Member States themselves.

As a partner to developing Member States engaged in mutual technical co-operation, the IAEA provides co-ordination assistance and technical backstopping in a context of furthering regional self-sufficiency. For instance, the international campaign to eradicate rinderpest from Africa counts on the IAEA, in co-operation with some national veterinary laboratories, to verify immunization levels and to identify rinderpest-free areas. These laboratories also function as regional training and diagnostic centres, supporting the goal of a rinderpest-free Africa by the year 2000.

Paks MTC Inaugurated

A WWER 440/213 dummy reactor to be used as the centrepiece of a Maintenance Training Centre (MTC) at Paks NPP in Hungary (see "Old parts serve new purpose", Inside TC, December 1996) was formally opened on 29 April. The MTC is unique because it is the only full-scale WWER reactor - like those that produce 50% of Hungary's electricity — used for hands-on training. Improved training on actual components will reduce maintenance shutdown time and help to avoid mistakes. This will improve safety for maintenance workers, who will spend less time in a radioactive environment.

The project was funded mainly by the Hungarian Government and the IAEA (at a total cost of $10 million) and by extrabudgetary funds from Japan, Spain, the United States and the European Union through its regional programme PHARE. The IAEA donated the essential components, bought at giveaway prices ($1 million) from cancelled reactor construction projects in Germany and Poland.

The impact of the project will not be limited to Hungary. Eight other countries in the region have 45 WWER reactors in operation, providing one-third to one-half of their electricity. The training programmes and facilities at Paks can be used to train NPP maintenance personnel from these countries as well as the staff at Paks, thus contributing to safer reactor operation throughout the region. The Czech Republic and Slovakia have already concluded a training agreement with Hungary, and there is the possibility of the IAEA supporting training through TC fellowships and scientific visits.

Mr. S. Fazakas (left), Hungarian Minister for Industry and Trade and Mr. Qian Jihui, IAEA Deputy Director General and Head of the Department of Technical Co-operation, inaugurate the MTC at Paks NPP. Credit: M. Samiei/IAEA

Guarding Against the Seismic Threat

Earthquakes have been a continuing concern for the nuclear energy sector worldwide. In the early years of nuclear power, seismic knowledge was very limited. But understanding of earthquake behaviour, along with instruments and methodologies to measure many seismic phenomena more accurately, has increased vastly over the past 30 years. New knowledge has triggered strengthening of the safety barriers of many nuclear plants. For example, the Diablo Canyon plant in quake-prone California was upgraded to withstand a prodigious shock of 0.76g ("g" value is acceleration of gravity in seismic speak) as a result of a major US assessment programme.

The nuclear industry worldwide is committed to significant safety margins in nuclear power plants. Selecting a suitable site alone can consume more than five years of studies and US$10-15 million. A wide range of disciplines — geology, volcanology, historical seismicity and geophysics — is deployed. They focus on the immediate area (5 kilometres radius), further away (25 km) and finally as far as 200 km away, and thus postulate the magnitude of an earthquake at the site with a "return period" of 10,000 years.

It is only on this basis that the plant design is completed. The seismic design basis (SDB) specifies the engineering that can withstand an earthquake equal to the "g" value of the site. Requirements were far less rigid in the early years of NPP construction. And although there has been no substantial earthquake damage to an NPP in decades of nuclear power generation (over 8,000 years in sum), the industry is not complacent. With over 10 times as many reactors in operation (443) as are being built (35), the principal seismic effort is on upgrading existing plants.

The IAEA's seismic safety programme has helped countries like Indonesia, Iran, Morocco and Pakistan, with rigorous site selection evaluation for planned nuclear power plants. But the bulk of activities is in the former USSR and eastern and central Europe. Substantial work has been carried out to reassess the seismic design bases of WWERs in Armenia, Bulgaria, Hungary and Slovakia, most of them older models. These studies show that all the original design bases had underestimated ground motion parameters. So they must all be revised upwards, and upgrades must meet the new SDBs. Armenia's nuclear power plant has to be upgraded to meet a rating of 0.35g.

Twenty years ago, a severe earthquake in the shock-prone Vrancea region of Romania slightly damaged the two operating WWER 440/230 reactors in Kozloduy, Bulgaria, some 400 kilometres away. The ground motion was estimated to have reached 0.1g. A number of seismic safety improvements were then implemented in the two units and also introduced in the two units (3 and 4) under construction at the time. The new rating for the plant is 0.2g.

Two sets of data are needed to formulate or re-evaluate an SDB. One relates to earthquakes that have occurred, going back as far back in time as possible; the other analyses tectonic faults that can produce them. "In most eastern (European) plants they had used only recent seismic activity, not historical seismicity," an IAEA expert analyses. "The limited database was not sufficient for the purpose of designing an NPP."

The newly revised IAEA Nuclear Safety Standards (NUSS) combine the two data sets, enabling them to be used together to assess the seismic capacity (ability to resist shock) of these plants and define what upgrades must be done to achieve the reassessed design basis. The upgrades fall into two categories: so-called "easy fixes" which can be done quickly and relatively inexpensively, and structural upgrades which are long term and more costly. So far only Kozloduy and Paks (Hungary) have completed the "easy fixes", while structural upgrades have begun in one unit in Bohunice (Slovakia).

The IAEA requests that a methodical work plan is adopted in each country, and implemented according to its timetable. An earthquake magnitude under the new SDB is calculated with a return period of 10,000 years. So a country may decide that delaying completion of this work by a few years is a reasonable risk. But indefinite delay is too long to accept.

Bulgaria's commitment to upgrading nuclear safety at Kozloduy has been impressive and brought it dividends too. The IAEA technical co-operation project in Kozloduy (1991-95) included help to complete seismological studies, mostly in the country but also in the Romanian earthquake zone. The Agency also helped to upgrade the plant's seismic instrumentation. The Bulgarians, with technical help from the World Association of Nuclear Operators and funds from the European Commission's PHARE programme, elaborated and implemented the "easy fix" programme for Units 1 and 2. The country also did similar improvements on units 3 and 4, with support from the United States. The experience gained in the process, including the detailed preparations for the "easy fix" upgrading of the four units, has enabled Bulgarian authorities to draw up a comprehensive programme for the structural upgrading of the Kozloduy plant.

INSIDE Technical Co-operation is researched and written for the IAEA by an independent journalist assigned by Maximedia. The stories may be freely reproduced. For more information contact: IAEA TC Programme Co-ordination Section, P.O. Box 100, A-1400 Vienna, Austria. Tel: +43 1 2060 26005; Fax: +43 1 2060 29633; e-mail: TCPROGRAM@IAEA.org