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GLOBAL TRENDS IN ADVANCED REACTOR DEVELOPMENTS, AND THE ROLE OF THE IAEA

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ABSTRACT

Due to further increases in the world's population along with further industrialization and economic development, global energy demand will surely continue to increase in the 21 century.

To assure that nuclear power remains a viable option in meeting energy demands in the near and medium terms, new reactor designs for all principle reactor lines and for different applications are being developed in a number of countries. Common goals for these new designs are high availability, user-friendly features, competitive economics and compliance with internationally recognized safety objectives.

World-wide, considerable efforts are being made to develop advanced nuclear power. 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$ 2 billion per year.

This paper gives an overview about nuclear power technology development programmes and projects in Member States and the role of the IAEA as a forum for informatic exchange and co-operative research.

I. INTRODUCTION

In the second half of the 20th century nuclear power has evolved from the research and development environment to an industry that supplies approximately 16.7% of the world's electricity. In these 50 years of nuclear development a great deal has been achieved and many lessons have been learned. At the end of 1999, according to data reported in the Power Reactor Information System, PRIS, of the IAEA, there were 436 nuclear power plants in operation and 39 under construction. Over nine thousand reactor-years of operating experience had been accumulated.

Due to further industrialization, economic development and projected increases in the world's population, global energy consumption will surely continue to increase into the 21st century. Based on IAEA's review of nuclear power programmes and plans of Member States, several countries, especially in the Far East, are planning to expand their nuclear power capacity considerably in the next 15-20 years.

The contribution of nuclear energy to near and medium term energy needs depends on several key issues. The degree of global commitment to sustainable energy strategies and recognition of the role of nuclear energy in sustainable strategies will impact its future use.

Technological maturity, economic competitiveness and financing arrangements for new plants are key factors in decision making. Public perception of energy options and related environmental issues as well as public information and education will also play a key role in the introduction of evolutionary designs. Continued vigilance in nuclear power plant operation, and enhancement of safety culture and international co-operation are highly important in preserving the potential of nuclear power to contribute to future energy strategies.

To provide balanced information on development of advanced nuclear power plants to all IAEA Member States, reports on different concepts being developed and the project status, as well as typical development trends throughout the world are published by the IAEA [1-15].

II. OVERVIEW OF GLOBAL DEVELOPMENT ACTIVITIES FOR ADVANCED NUCLEAR POWER PLANTS

World-wide, considerable efforts are being made to develop advanced nuclear power. 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 $ 2 billion per year.

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. In particular, a step increase in cost arises from the need to build a reactor as part of the development programme (see Figure 1).

A. Overview of Water-Cooled Reactor Development Programmes

Worldwide there is considerable experience in LWR and HWR technology. Of the operating plants, 345 are LWRs totaling 305 GWe and 31 are HWRs totaling 15.88 GWe. The experience and lessons learned from these plants are being incorporated into new water cooled reactor designs which are under developed in a number of countries.

Most of the effort is on evolutionary designs aimed at achieving certain improvements over existing designs through small to moderate modifications. Utility requirements documents have been formulated to guide these activities by incorporating this experience with the aim of reducing costs and licensing uncertainties by establishing a technical foundation for the advanced designs. For evolutionary designs, there is a general drive for simplification, larger margins to limit system challenges, longer grace periods for response to emergency situations, improvement of the man-machine interface systems, shorter construction and improved maintainability. All evolutionary designs incorporate features to meet stringent safety objectives by improving severe accident prevention and mitigation. Several evolutionary designs have reached a high degree of maturity: nuclear regulatory authorities have certified some designs, and some are progressing through an optimization phase to reduce capital cost. In some cases design optimization leads to higher plant output to take advantage of the economy of scale, while in other cases, economic competitiveness is pursued through simplification resulting from reliance on passive safety systems.

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 minimise 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.

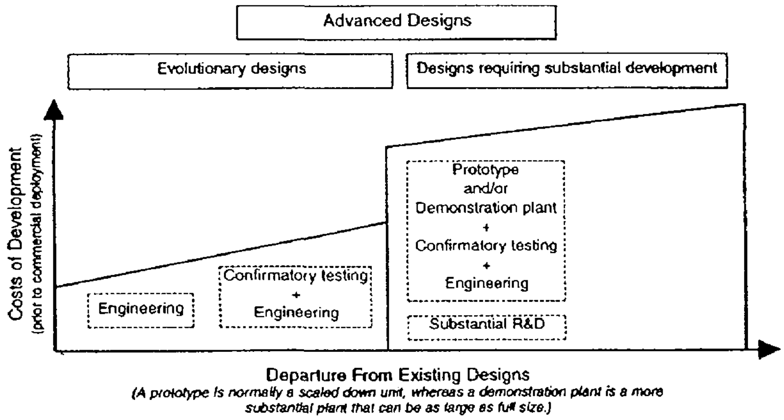

Figure 1. Efforts and development costs for advanced designs versus departure from existing designs (Terms are excerpted from Ref. 16).

At the beginning of 2000:

LWRs in operation	345
LWRs under construction	25
Number of countries with LWRs	28
Generating capacity, GW(e)	305
Operating experience with LWRs, reactor-years	6749

Advanced light-water reactors (ALWRs): Designs for ALWRs are being developed in a number of countries as summarized below.

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 co-operation with the US Department of Energy and 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 co-operation with EPRI and reactor design organizations, initiated a design certification programme for evolutionary plants based on a new licensing process, followed in 1990 with 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.

In May of 1997 the System 80 + plant of ABB Combustion Engineering and the ABWR plant of General Electric received Design Certification from the U.S. Nuclear Regulatory Commission. The Westinghouse AP-600 design, a mid- size plant with passive safety systems, received Design Certification from the NRC in December 1999. The certification of these 3 designs highlights the succes of the U.S. Department of Energy's design certificaion program for large evolutionary plants. Also the first-of-a-kind-engineering, FOAKE, programme was completed for the ABWR in September 1996 and similar work on the AP-600 was completed in 1998. The power company in Taiwan, China, recently selected the USA's ABWR design for two new units slated for operation in 2004.

France and Germany: In Europe, Framatome and Siemens with their joint company, Nuclear Power International, together with Electricité de France and the group of "nuclear" German utilities have worked out the design of a new advanced reactor, the European pressurized-water reactor (EPR), a 1545 MWe PWR with enhanced safety features. This reactor is designed to meet utility requirements endorsed by the major utilities of the European countries as expressed in the European Utilities Requirements (EUR) document, and the common safety requirements of the German and French Safety authorities. The basic design was completed at the end of 1997. The EPR is ready to be offered on the international market.

Siemens is also, together with German utilities, engaged in the development of an advanced BWR design, the SWR-1000, an evolutionary BWR which incorporates 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 and the BWR 90+ designs as upgraded versions 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 KNGR is being developed on the basis of experience with the 1000 MWe Korean Standard Nuclear Plants (KSNPs). The first two KSNPs, Ulchin 3 and 4, were connected to the grid in January and December 1998, respectively. Four more KNSPs are under construction – two at Yonggwang, and two more at Ulchin (as of October, 1999).

An optimized design for KNGR is to be followed by a detailed design for standardization in 1999. According to the mid-and-long term construction plan of power plants in the Republic of Korea, the first KNGR is scheduled for operation in 2010.

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 co-operation 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 licenses for VVER-640 units have been issued by the Russian regulatory body Gosatomnadzor for the Sosnovy Bor site (near St. Petersburg) and for the Kola NPP-2 site (Murmansk region). Construction of 1000-MWe VVERs is being planned in the People's Republic of China, India and Iran.

Japan: In Japan, the development of the ABWR started in 1978 as an international co-operation between five BWR vendors. The resulting conceptual design was received favourably by TEPCO and other Japanese utilities, and as a result, the ABWR was included in the third standardization programme of Japan from 1981. Preliminary design and numerous development and verification tests were carried out by Toshiba, Hitachi and GE together with six Japanese utilities and the Japanese Government. Two ABWRs, the Kashiwazaki-Kariwa units 6 and 7 were subsequently ordered by TEPCO and have been successfully taken into commercial operation in November 1996 and July 1997 respectively. Two more ABWRs are under licensing review in Japan, and several more ABWRs are planned.

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 1530-MWe advanced PWR is being developed by Japanese utilities together with Mitsubishi and Westinghouse, 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.

China: In China, the Nuclear Power Institute (Chengdu) is developing the AC-600 advanced PWR, which incorporates passive safety systems for heat removal, based on experience in the design of the 610 MWe Qinshan II plant. Experiments on critical heat flux at low flow rates, characteristics of core injection from core makeup tanks, passive containment cooling, passive emergency core heat removal on the secondary side, as well as several other tests, have been completed.

Heavy-water moderated reactors (HWRs): In addition to light water-cooled reactors, the technology for HWRs has also proven to be economic, safe, and reliable. Nearly 7% of all operating plants are HWRs. A mature infrastructure and regulatory base has been established in several countries. 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.

At the beginning of 2000:

HWRs in operation	31
HWRs under construction	7
Number of countries with HWRs	7
Generating capacity, GW(e)	15.88
Operating experience with HWRs, reactor-years	645

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 materials is limited 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; this, and the high neutron economy, give heavy water reactors great fuel cycle flexibility. Safety performance has been 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: India currently has 10 operating HWRs with a total capacity of 1.8 GWe. In addition, two HWRs of 220 MWe each are under construction (the Kiaga-1 unit and the Rajasthan-4 unit). These plants are scheduled to achieve commercial operation in 2000 and 2001. Furthermore, construction of two 500 MWe units at Tarapur is underway. This HWR design takes advantage of experience feedback from the 220-MWe HWR plants of indigenous design operating in India. An advanced HWR is also under development in India. This is a vertical pressure tube reactor design utilizing heavy water moderator, boiling light water coolant, thorium based fuel and incorporating passive safety systems. This HWR design takes advantage of experience feedback from the 220-MWe HWR plants of indigenous design operating in India.

Republic of Korea: Unit-4 of Wolsong plant, a 700 MWe CANDU-6 started commercial operation in October 1999 to bring Korea's installed HWR capacity to 28 MWe in four units.

During 1999 two HWRs, in India and the Republic of Korea came on line, and one HWR in India reached criticality. Heavy water reactors are also successfully operating in Argentina, Romania and Pakistan, and two CANDU-6 are under construction on Qinshan, China.

B. Overview of Gas-Cooled Reactor Development Programmes

The initial development of gas cooled reactors was on CO_2 cooled systems. In order to achieve higher efficiency, more recent development has been on helium cooled systems (HTGRs).

GCRs in operation	34
Generating capacity, GW(e)	11.78
Operating experience with gas-cooled reactors, reactor-years	1376

HTGRs are a unique technology offering both highly efficient generation of electricity with direct cycle helium turbines, and production of high temperature process heat enabling nuclear energy to be used for production of H_2 as a clean energy supply. Therefore HTGRs can expand the use of nuclear energy into the process heat market in industrialized countries and they can be introduced as SMRs for electricity production in developing countries. Current development is focused precisely on this approach: the HTGR is being developed in Japan for high temperature process heat applications; and it is being developed in China, and possibly soon in South Africa for electricity production. This development is proceeding on the basis of technology transfer from Germany, the USA, Russia, France and the UK.

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 was 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.

Russian Federation, United States, France, Japan: MINATOM, General Atomics, Framatome and Fuji Electric have combined their efforts for the co-operative development of the gas turbine-modular helium reactor (GT-MHR). This plant features a 600 MWth helium cooled reactor as the energy source coupled to a closed cycle gas turbine power conversion system. The net efficiency of this advanced nuclear power concept is 47%. Substantial progress in the development of components such as magnetic bearings and fin-plate recuperators make this type of HTGR plant a feasible alternative for future consideration in the production of electricity. This plant is under consideration for the purposes of burning plutonium and for commercial deployment.

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, economic and safely evaluation of a helium-cooled pebble bed modular reactor directly coupled to a gas turbine power conversion system. One module will have an output of 114 MW(e). Ten modules will be combined for a 1140 MW(e) Nuclear Power Station. This study has been performed with support from the IAEA.

China and Japan: In China and Japan, HTGR development focuses on construction and operation of test reactors. Construction of China's High Temperature Reactor (HTR-10) at the

Institute of Nuclear Energy Technology (INET) continues with initial criticality anticipated for the end of 2000. 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 development programme is the High Temperature Engineering Test Reactor (HTTR) at the Japan Atomic Energy Research Institute (JAERI) site in Oarai, Japan. Initial criticality of the HTTR was achieved in November 1998. This 30-MWth helium-cooled reactor is being utilized to establish and upgrade the technology for advanced HTGR development, and to demonstrate the effectiveness of selected high temperature heat utilization systems.

C. Overview of Liquid Metal-Cooled Reactor Development Programmes

The feasibility of a nuclear chain reaction involving only fast neutrons was recognized from the earliest days of nuclear power in the 1940s. As a matter of fact, a fast reactor, the EBR-1 in the USA, delivered the first electrical current ever produced through fission processes. The driving force behind the R&D work in the field of fast reactors was the realization that fast reactors could be used for breeding fissile material from fertile. This provided the key to utilizing the enormous world-wide energy reserve represented by uranium-238, opening the prospect of a virtually non exhaustible source of energy.

The development of civil fast reactors started in several countries, notably the USA, the USSR, the UK and France, in the late 1940s. This involved test reactors such as CLEMENTINE and EBR-1in the USA, and BR-2 in the USSR. Subsequently, experimental reactors such as EBR-2, Fermi and FFTF (USA), BR-10 and BOR-60 (USSR), Rapsodie (France), KNK-II (Germany), JOYO (Japan), FBTR (India), and DFR (UK) were constructed from the 1950s to the early 1970s, leading to demonstration or prototype power reactors such Phénix (France), PFR (UK), BN-350 (USSR-Kazakhstan), BN-600 (USSR-Russia), MONJU (Japan) and PFBR (India), and finally to the only full-scale power plant, Superphénix (France).

In the earliest days great importance was attached to the breeding of fissile material, but the increasing availability of low cost uranium from the 1980s onwards shifted the emphasis to include other uses for fast reactors both in the critical and subcritical mode, particularly for the control of plutonium stocks and the treatment of radioactive wastes. In spite of these additional functions the main long term importance of fast reactors as breeders, essential to world energy supplies, remains unchanged.

LMRs in operation	3
LMRs under construction	2
Number of countries with LMRs	3 (+1 with a test reactor)
Generating capacity , GW(e)	1.039
Operating experience with LMRs, reactor-years	141

Technology development programmes for LMFRs are proceeding in several countries:

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, thermalhydraulics, 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. A preliminary design has been completed in 1997, and licensing efforts are underway with the submission of the Preliminary CEFR Safety Analysis Report in late spring of 1998.

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 (CAPRA and CADRA projects). The current programmes on operation of the 250 MW(e) Phénix reactor reflect these requirements. One objective of extending the lifetime of the Phénix reactor till 2004 is to perform the necessary irradiation experiments. The 1200 MW(e) Superphénix reactor has recently been shut down.

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 was 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 early 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: In the Republic of Korea, the LMFR development programme is considered as an important part of the national long-term R&D programme. The Republic of Korea plans to develop the conceptual design of its first fast-breeder reactor, the 330 MWe Kalimer plant, by 2001, and the basic design by 2006, for construction soon after 2010.

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 further 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 on the basis of new BN-800 fast reactors.

United States: A promising integral fast reactor (IFR) concept, comprising the LMFR and its entire fuel cycle, has been developed at the Argonne National Laboratory (ANL) and General

Electric Company over the past two decades. A distinguishing element of the IFR concept is its unique fuel cycle based on metallic fuel and pyrometallurgical processing. At ANL, an effective fuel cycle technique has been developed whereby spent fuel is reprocessed and new fuel is fabricated at the reactor sites. The plutonium is not separated from the higher radioactive actinides; these are recycled together in the reactor and never leave the reactor site. Advantages of the IFR system are in areas of (i) fuel performance, (ii) passive safety, (iii) economics, (iv) waste management potential, and (v) proliferation resistance. When the first LMFRs were constructed in the 1950s, it was expected that the burn-up potential of metallic fuel would be limited to 3-5 % of heavy atoms. In fact, by using a U-Pu-1-% Zr alloy and ferritic-martenistic HT9 cladding and duct, a burn-up of about 20 % has been achieved in EBR-II. All irradiation results in EBR-II and FFTF have demonstrated reliable performance of metallic fuel and the potential to achieve high burn-up in prototypical fuel elements.

D. Small and Medium Sized Reactors

Small and medium sized reactors (SMRs) are of particular interest for non-electrical applications of nuclear energy, such as desalination of seawater and district heating. But SMRs are also a suitable option for electricity generation in countries with small electricity grids or for remotely located areas such as for populated small islands. Many reactors described in chapter II are in the SMR size range, i.e. with an output of less than 700 MWe.

In several countries there is an emerging interest in small and medium sized reactors which do not require on-site refuelling. These reactors may either have a long core life-time or are returned to the vendor for maintenance and refuelling.

Barge mounted reactors are a typical example of this SMR category. They could be supplied to countries having an immediate need for energy, which do not yet have a fully implemented nuclear infrastructure as needed for large sized plants. Barge mounted reactors could be operated under the auspices of the vendor and since no on-site refuelling is required they create a new approach to proliferation resistance. Transportable barge mounted SMRs offer at the same time the potential for the reduction of the financial risk compared to conventional nuclear power plants.

Currently a project with barge mounted reactors is being implemented in the Russian Federation to supply electricity and heat for Pevec in the northern part of Siberia. The reactor considered in the frame of this project is a redesigned version of the proven KLT-40, which has been used for the propulsion of ice-breakers.

The Agency is currently investigating options for providing an umbrella for co-operation between countries that implementing programmes of innovative reactors and fuel cycles. Most of those reactors are in the SMR range and their design features include further improved economics, more proliferation resistance, easy operability and maintenance and further improved safety. Innovative fuel cycles include high burn up cores, high converters and alternative fuel cycle systems, including inert matrix fuel and thorium.

III. NUCLEAR DESALINATION

While availability of potable water is an important prerequisite for socio-economic development, about 1/3 of the world's population is suffering from inadequate potable water supplies. Seawater desalination with nuclear energy could help to cope with the fresh water shortages and several countries are investigating nuclear desalination.

In Argentina a small reactor, which is planned to be coupled to a desalination process is under design (CAREM). In Canada activities include desalination technology development and studies for coupling to CANDU reactors, and in cooperation with the Russian Federation, to a small reactor formerly used for ship propulsion. In China a study has been initiated for a heating reactor combined with a desalination unit that could produce 150,000 m^3/d of potable water. In India a desalination unit will be coupled to an existing PHWR at Kalpakkam. The first draft of the modified Preliminary Safety Assessment Report has been presented to the regulatory body and detailed engineering of the coupling system is under way. Civil work for the desalination systems has started and the commissioning is foreseen for year 2001. In Japan nuclear desalination facilities are in operation and have accumulated about 100 reactor years of operational experience. The Republic of Korea is about to complete its conceptual design of the System-Integrated Modular Advanced Reactor Project this year. A desalination unit is planned to be coupled to the reactor. The feasibility study for a nuclear desalination plant in Morocco based on a 10 MW heating reactor from China was completed last October. The site has been identified and economic assessments have been completed. An agreement has been signed by China and Morocco to implement the project. Russia is investigating the development of the concept of a floating power unit based on KLT-40 reactors.

IV. IAEA ACTIVITIES ON NUCLEAR POWER TECHNOLOGY DEVELOPMENT

As an international forum for exchange of scientific and technical information, the IAEA plays a role in bringing together experts for a world-wide 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, and to provide balanced and objective information to all Member States on advances in reactor technology, the IAEA periodically prepares status reports on advances in technology for each major reactor line.

Co-operative research: The IWGs advise the IAEA to establish international co-operative research projects (CRPs) in areas of common interest. These co-operative efforts are typically are three to five 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.

Major Meetings: Last year the Agency convened the IAEA Symposium on Evolutionary Water Cooled Reactors: Strategic Issues, Technologies and Economic Viability in Seoul, Republic of Korea, in November 1998. The Symposium was hosted by the Korea Electric Power Corporation on behalf of the Government of the Republic of Korea in co-operation with the OECD Nuclear Energy Agency, the Uranium Institute, the Korean Nuclear Society and the Korea Atomic Industrial Forum. Topics addressed included the global energy outlook, the role of nuclear power in sustainable energy strategies, financing of nuclear plant projects, projected power generation costs, social-political factors, safety requirements, key features of evolutionary designs, and keys to economic viability (such as simplification, standardization, advances in construction and project management, and effective management of plant operations).

The Symposium highlighted the importance of continued international co-operation in the development and application of nuclear power for peaceful uses throughout the world. The challenges facing nuclear power in the future are:

- to continue to achieve the highest level of safe operation of current plants,
- to implement high level waste disposal,
- to establish a sound basis for defining the potential of nuclear power to contribute to sustainable development,
- to achieve further technological advances to assure that future nuclear plants will be economically competitive with fossil alternatives, especially in deregulated and privatised electricity markets, and
- to develop economical small and medium sized reactor designs to provide the nuclear power option to developing countries which have small electricity grids, and also for non-electric applications such as seawater desalination.

For 2001 the Seminar on Status and Prospects for Small and Medium Sized Reactors is planned to be held in Egypt to review and discuss the status of technology developments and applications for SMRs and to identify their challenges and solutions into the 21st century.

V. CONCLUSIONS

To assure that nuclear power can meet world energy needs in the near and medium term, considerable development activities are being carried out for each major reactor line, building on the large experience base. New designs have been, and are being, developed to meet user requirements which include economic competitiveness while meeting stringent safety objectives. Technology advances are contributing both to the safety targets as well as to economic goals.

The IAEA's role is to provide all Member States with an international source of balanced, objective information on advances in reactor technology, and to provide an international forum for information exchange and co-operative research.

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