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TRENDS IN ADVANCED REACTOR DEVELOPMENT AND THE ROLE OF THE IAEA
MISE AU POINT DE REACTEURS AVANCES : TENDANCES ET ROLE DE L'AIEA
TENDENCIAS EN EL DESARROLLO DE REACTORES AVANZADOS Y EL ROL DEl OIEA

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Abstract
Extrait
Sinopsis

Many countries are already heavily reliant on nuclear energy for electric power production; as of December 1991*, there were 421 nuclear power plants in operation worldwide with a total net capacity of 326 GW(e). In several countries, nuclear generated electricity has already reached a high percentage of the total generated electricity, e.g. in 1990 in France 74.5%, in Belgium 60.1%, in the Republic of Korea 49.1%. In the USA, the country with the highest amount of installed nuclear power generating capacity in the world (101 GW(e)), 20.6% of the electricity is generated by nuclear power.

The continuously increasing world population needs additional energy supply as an important prerequisite for further socio-economic development. This is especially true in developing countries where the per capita energy use is only a very small fraction of that in developed countries. Nuclear energy is an essentially unlimited energy resource with the potential to provide this energy in the form of electricity, district heat and process heat under environmentally acceptable

* Source: Preliminary non-governmental information as of 31 December 1991, IAEA PRIS data base.

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conditions. However, this potential will be realized only if nuclear power plants can meet the challenges of increasingly demanding safety requirements, economical competitiveness and public acceptance.

Worldwide a tremendous amount of experience has been accumulated during development, licensing, construction and operation of nuclear power reactors. The experience forms a sound basis for further improvements. Nuclear programmes in many countries are addressing the development of advanced reactors which are intended to have better economics, higher reliability and improved safety in order to overcome the current concerns of nuclear power.

Advanced reactors are being developed for all principal reactor types, i.e. the light and heavy water-cooled reactors, the liquid-metal-cooled reactors and the gas-cooled reactors. Some of these developments are primarily of an evolutionary nature, i.e. they represent improvements in component and system technology, and in construction and operating practices as a result of experience gained with presently operating plants. Other developments are also evolutionary but with some incorporation of innovative features such as providing passive systems for assuring continuous cooling for removal of decay heat from the reactor core.

If there is a revival of nuclear power, which may be dictated by ecological and economical factors, advanced reactors now being developed could help to meet the large demand for new plants in developed and developing countries, not only for electricity generation, but also for district heating, desalination and for process heat.

The IAEA, as the only global international governmental organization dealing with nuclear power, has promoted international information exchange and international co-operation between all countries with their own advanced nuclear power programmes and has offered assistance to countries with an interest in exploratory or research programmes. In the future the IAEA could play an even more important role.

INTRODUCTION
INTRODUCTION
INTRODUCCION

Nuclear energy has an important role to play in supplying the growing world population with energy. The desire to conserve fossil fuels, which at the same time are valuable raw materials, the commitment to decrease CO_2 emissions below certain levels and the limited prospects of large scale use of renewable energy sources tend to emphasize the potential contribution of nuclear energy. However, this form of energy will be successful only under certain conditions: it must meet very strict safety requirements, it must be economically competitive, and it must be acceptable to the public. The nuclear industry is faced with a demanding challenge in attempting to meet these conditions.

One of the ways to meet future energy requirements could be a gradual introduction of advanced reactors into the world's nuclear power system. Much development work is going on in several countries, with participation of both governmental and private industries. Advanced reactors are being developed for all principal reactor types, i.e. the light and heavy water-cooled reactors, the liquid-metal-cooled reactors and the gas-cooled reactors [1,2,3,4]. Some of these developments are primarily of an evolutionary nature, i.e. based on improvements in the technology, in components and systems, and in construction and operation as a result of experience gained with presently operating plants. Other developments are also evolutionary but typically incorporate innovative features such as passive systems for assuring continuous cooling for removing decay heat from the core. Designs incorporating such innovative features may require construction of prototype or demonstration reactors before commercialization.

1. NUCLEAR POWER DEVELOPMENT TRENDS
TENDANCES DE L'ELECTRONUCLEAIRE
TENDENCIAS DEL DESARROLLO DE ENERGIA NUCLEAR

Increased attention to nuclear power development is being given not only by the governments and industrial entities in nations with an already well established nuclear power production industry, but also by those nations seriously considering an expansion of or entering into nuclear power implementation. The development trends for all reactor concepts are clearly reflecting the influence of past experience and the revised development goals for the future.

1.1 Light Water-Cooled Reactors
Réacteurs refroidis à l'eau ordinaire
Reactores Refrigerados por Agua Natural

The current Western light water-cooled reactor (LWR) technology has proven to be economic, safe and reliable. The LWR has a mature infrastructure and regulatory base in several countries. Over 75% of all current operating plants are LWRs. LWRs also have the highest percentage of the total world reactor operating experience. Most industrialized countries continue to develop large size units, with power outputs above 900 MW(e), as advanced LWRs (ALWRs) for the 1990s. These evolutionary ALWR designs result from continuous upgrading and improvement based on experience gained from current models. For example, the N4 model (1400 MW(e)), which is now under construction in France, derives directly from the standardized P4 series (1300 MW(e)), while achieving a reduction of 5% in cost per installed kilowatt compared with the P4 series. In Germany the "CONVOY" plants are a group of three standard pressurized water reactors of the 1300 MW(e) size. The advanced features of the "CONVOY" plants are mainly in the engineering and project management associated with nuclear power plant construction. The Westinghouse-Mitsubishi Advanced Pressurized Water Reactor (APWR-1350 MW(e)), the British "Sizewell-B" PWRs (1250 MW(e)), the ABB-Combustion Engineering "SYSTEM 80 PLUS" (1300 MW(e)) and the General Electric-Hitachi-Toshiba Advanced Boiling Water Reactor (ABWR-1360 MW(e)) are further examples of the large size evolutionary ALWR.

Mid-sized ALWRs in the 600 MW(e) range are also being developed with greater emphasis on passive safety features. Within the context of definitions in this paper, both the larger and mid-sized ALWRs are considered to be evolutionary designs, in that none will require a prototype. Examples of these mid-sized passive ALWRs include the Westinghouse Advanced Passive PWR (AP-600) and the General Electric Simplified Boiling Water Reactor (SBWR).

An important aspect of the United States programme was initiated in 1984 by the Electric Power Research Institute, an organization of U.S. utilities. Several foreign utilities have also participated in the effort. A comprehensive set of user requirements was compiled and the designs of ALWRs to meet these requirements are being developed. This design work is being partly supported by the U.S. Department of Energy. Utility requirements were established for both BWRs and PWRs, of both large (outputs around 1200 MW(e)) and mid-sized reactors (outputs around 600 MW(e)). Design certification from the U.S. Nuclear Regulatory Commission is a key feature of this programme and it is contemplated that standardized units could be commercially offered in the 1990s as design certification is obtained.

All of these ALWRs incorporate significant design simplification, increased design margins, and various technological and operational procedure improvements, including better fuel performance and burnup, better man-machine interface using computers and improved information displays, greater plant standardization, improved constructability and maintainability, and better operator qualification and simulator training. The result of these improvements will expand on the already manifested improvements in availability and the lower number of challenges to safety systems.

Further work along these lines is being done in Europe. Initiated in 1989 by Electricité de France, the REP 2000 programme should lead to the specification of European utilities' requirements. On the vendor side, FRAMATOME and SIEMENS established a joint company, Nuclear Power International (NPI), which is developing a new product with enhanced safety features, and intend to have it 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 to a broader basis. In Sweden, ABB Atom, in cooperation with the utility Teollisunden Voima Oy (TVO) of Finland, is developing the BWR 90 as an upgraded version of the boiling water reactors operating in Sweden.

In the Russian Federation, design work on the evolutionary VVER-92, an upgraded version of the VVER-88, has been started and another design, the VVER-91, is being developed in cooperation with Finland. The Russian Federation is also developing the evolutionary VVER-500 design along the same lines as the AP-600 and a more innovative, integral design, the VVER-600.

An innovative approach for next generation light water-cooled reactors is being taken by ABB-Stom, the developers of the PIUS reactor. The conceptual design for PIUS is for a mid-size power unit of about 600 MW(e), although smaller sizes are certainly possible. The approach to enhanced safety in this reactor is based on the principle that the ability to shut down the reactor and provide continuing core cooling to remove decay heat after accidents could be entirely passive. The PIUS principle is based on having a large volume of borated water available to shutdown and cool the reactor core. This borated water is separated from the primary water coolant by density locks during normal operation but naturally convects through the core during any shutdown. Several other innovative designs, both of the boiling and pressurized water reactor types, using the PIUS passive core shutdown and cooling principles, are also being considered. The ISER (University of Tokyo) and the SPWR (Japan Atomic Energy Research Institute) concepts use the PIUS principle on smaller units inside steel vessels. Proof of the PIUS principle would probably require a demonstration plant, although considerable loop-type verification work has already been performed.

With delays apparent in the large scale deployment of breeder reactors, mostly from cost considerations, improvement in uranium resource utilization has become another element in the evolutionary development of LWRs. Some improvements involve relatively limited changes to optimize core designs for improved uranium utilization with the once-through cycle. These approaches should have low economic risks and some have been incorporated in existing plants. Further improvement in resource utilization could be obtained by more widespread application of plutonium recycling in LWRs. Confirmation of technical and economic feasibility and safety of evolutionary developments for LWRs is expected shortly from validation studies and development work in progress in several countries, including the USA, Japan, Germany and, in particular, France. Many of these modifications, if proven satisfactory, could be applied to existing reactors within the next three to five years.

1.2 Heavy Water-Cooled Reactors
Réacteurs refroidis à l'eau lourde
Reactores Refrigerados por Agua Pesada

Heavy water-cooled reactor (HWR) technology has also proven to be economic, safe and reliable. A mature infrastructure and regulatory base has been established in several countries, notably in Canada, the pioneer in the development of the HWR concept. Approximately 7% of all current operating plants are HWRs. Two types of commercial pressurized heavy water-cooled reactors have been developed. Both the pressure tube and pressure vessel variants have been fully proven. Sizes in the output range of a few hundred MW(e) up to 900 MW(e) are available. Lifetime capacity factors of most of them have been among the best of all commercial reactor types. Safety performance has also proven very good. The promise of low fuelling costs arising from the inherent neutron economy of heavy water moderation has been demonstrated.

The continuing design and development programmes for HWRs in Canada are primarily aimed at reduction of plant costs and an evolutionary type of enhancement of plant performance and safety along lines similar to the LWR programme. These designs include the 450 MW(e) CANDU 3 and the 665 MW(e) CANDU 6 MK2. Also under development are the 500 MW(e) reactor in India and the 380 MW(e) ARGOS under joint development by an engineering firm in Argentina and Siemens in Germany. Work is also proceeding in Japan on 600 MWe and 1000 MWe ATRs, a heavy water moderated, boiling light water-cooled, pressure tube reactor.

1.3 Gas-Cooled Reactors
Réacteurs refroidis au gaz
Reactores Refrigerados por Gas

With the completion of the Heysham 2 and Torness Stations in the United Kingdom, the Advanced Gas Cooled Reactor (AGR) programme, pioneered by the UK, appears to have come to an end. Further development work on this carbon dioxide cooled system will be concentrated on improvements in plant performance and life extension studies of existing plants.

The experience with the early helium cooled High Temperature Gas-Cooled Reactors (HTGRs), the Dragon plant in the United Kingdom, the AVR in Germany and Peach Bottom in the USA was very satisfactory and proved the capability of several of the unique features of this type of system. The experience with the later HTGRs, Fort St. Vrain (330 MW(e)) in the USA and the THTR-300 (300 MW(e)) in Germany, was not entirely satisfactory. The problems which resulted in the termination of operation of these plants were not related to the basic reactor concept of helium cooling, graphite neutron moderation, the use of graphite as a structural material, or from any safety concerns but were primarily related to technical and economic problems with first-of-a-kind systems and components. The development of HTGRs is proceeding in the USA, Germany, the Russian Federation and Japan. Most of the effort is concentrated on small modular HTGR designs with an individual power output capability of 80 MW(e) up to about 170 MW(e).

The motivation for the present effort comes almost entirely from a critical examination of the requirements evolving from the objective of enchanced safety for future nuclear plants. Satisfying these requirements formed the basis for the smaller power output of individual power-producing modules and the reactor core configuration of each module. Emphasis has also been placed on other modular features of the design with a maximum use of factory fabrication, as opposed to field construction, for better quality control and time and cost savings. Separation of the HTGR nuclear systems from the majority of the plant, is intended to yield significant cost savings.

The key features of the HTGR which permit these characteristics are the benign helium coolant, the large mass of graphite moderator (hence, low power density) closely coupled to the fuel, the always negative power coefficient and, particularly, the fuel itself, which is in the form of small particles individually coated with multiple layers of ceramic material. This fuel is capable, along with the graphite moderator, of withstanding very high temperature without losing integrity.

It is recognized that the unique features and characteristics of the modular HTGRs will likely require prototype demonstration prior to design certification and commercialization and hence programmes in the USA, Germany and the Russian Federation are proceeding accordingly. With the relatively small size of each power-producing module, it is possible to contemplate such a demonstration with just one module with a later expansion into a multi module plant at the same site for commercial purposes.

The HTGR programme in Japan, although recognizing the potential for higher quality steam production and higher efficiency electricity generation, is nevertheless aimed primarily in the direction of proving the capability for even higher core outlet temperatures for the helium coolant (up to 950°C) with the view to a large number of industrial process heat applications. A small test reactor, the 30 MW HTTR, is presently being constructed in Japan for tests related to this objective.

1.4 Liquid Metal-Cooled Reactors
Réacteurs refroidis au métal liquide
Reactores Refrigerados por Metal Líquido

The deployment of liquid metal fast reactors (LMFR) as breeder reactors as well as for electricity generation has not gained the momentum expected, owing to the availability of adequate low cost uranium resources to meet near and mid-term demands. Nevertheless, there is an awareness in the industrialized countries that breeder reactors will be needed in the early decades of the next century particularly when large scale deployment of nuclear energy is necessary to meet growing energy demands.

In the interim, experience continues to be gained from the more than 200 reactor-years to date of operating experience from experimental and mid-size LMFR power units. The design development of advanced versions is also continuing, with due recognition to the requirements for the next generation of nuclear power plants. Work is also continuing on fuel cycle development with emphasis on extending fuel burnup and demonstration fuel cycle closure. Most of the fuel cycle development is on mixed oxide, but recent developments in the USA on the use of ternary metallic (U-Pu-Zr) fuel and the associated pyroprocessing of spent fuel are showing promise. A notable feature of pyroprocessing is that the majority of the long-life actinide elements which accompany plutonium through the process can subsequently be recycled into reactors for burning, being converted by fission into short-lived fission products, and thereby removed from the waste stream to facilitate waste disposal activities.

Design development in Europe, Japan and the Russian Federation is following the traditional path of considering large designs fuelled with mixed oxides. In Europe and in the Russian Federation, 1500-1600 MW(e) units are being developed with component design, plant design and fuel cycle following an evolutionary pattern from the operation of the Phenix and Superphenix in France, the PFR in the UK and the BN-350 and BN-600 in the Russian Federation. Major efforts are under way at this time to make better use of the philosophy of passive safety in these designs. One example is the European Fast Reactor (EFR) design, which includes a passive decay heat removal system via air coolers.

The efforts in Japan and India are concentrated on smaller units as the next step in design evolution. With the 280 MW(e) MONJU prototype reactor expected to go critical in 1992, Japan's next step is the development of a loop-type demonstration reactor. India is proceeding from its Fast Breeder Test Reactor (FBTR) with the follow-up design of a 500 MW(e) pool type prototype (PFBR).

With the demise of the Clinch River Breeder Reactor (CRBR) in the early 1980s, the liquid metal reactor programme in the USA initially proceeded down many advanced design avenues. The main thrust of the programme is now on a modular type concept, PRISM, originated by the General Electric Company. The development activities are focused on providing a reactor with improved safety and economics and an attractive waste management option. Each power block of the proposed system in comprised of three 471 MW(th) reactor modules connected to a single 465 MW(e) turbine generator. The plant has many innovative characteristics, including the use of the ternary metallic fuel cycle, inherent reactor shutdown by thermal and reactivity response, passive decay heat removal, and other construction and operational type characteristics claimed for such modular concepts. The programme is proceeding with the conceptual design, prelicensing stage of this concept with the intent of obtaining design certification following extensive testing of a full scale prototype module.

2. BROADER APPLICATIONS OF NUCLEAR ENERGY
APPLICATIONS DE L'ENERGIE NUCLEAIRE EN GENERAL
APLICACIONES DE LA ENERGIA NUCLEAR A CAMPOS MAS AMPLIOS

At present, about thirty percent of the world's primary energy consumption is used for electricity generation, about fifteen percent is used for transportation and the remaining fifty five percent is converted into hot water, steam and heat. This shows that the potential for applications of nuclear energy in the non-electric energy sector is quite large, although currently only a few nuclear plants are being used for non-electric applications with a total capacity of only 5 GW(th) to supply hot water and steam. Non-electric applications of nuclear energy are discussed in detail in another paper [5] at this conference. The following presents a summary of these applications, and provides some examples.

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

Up to about 550°C, the heat can be supplied by steam at reasonable working pressures; above that, the heat must be supplied by other energy carriers. Long term strength capabilities of metallic reactor materials set an upper limit of about 1000°C for nuclear supplied process heat. Industrial processes, for example steel production, which require temperatures above 1000°C can utilize nuclear energy only via secondary energy carriers such as electricity, hydrogen and synthesis gas.

Water cooled reactors offer heat up to about 300°C. These types of reactors include pressurized-water reactors (PWRs), boiling-water reactors (BWRs), pressurized heavy-water reactors (PHWRs) and light-water-cooled, graphite-moderated reactors (LWGRs). Liquid metal cooled fast reactors produce heat up to about 540°C. Gas-cooled reactors provide even higher temperatures, about 650°C for advanced gas-cooled, graphite moderated reactors (AGRs), and up to 950 to 1000°C for high-temperarture gas cooled reactors (HTGRs).

There is considerable incentive to make use of the capability of nuclear plants to provide co-generation of electricity, steam and heat for residential and industrial purposes [6]. Experience in cogeneration with water cooled reactors has been gained in the Russian Federation, China, Canada, Czechoslovakia, Switzerland, Germany, Hungary and Bulgaria. One of the largest uses of nuclear process steam occurs at the Bruce Nuclear Power Development Facility in Ontario Canada. The CANDU PHWRs at this site are capable of producing 6000 MWe of electricity as well as process steam and heat for use by Ontario Hydro and an adjacent industrial energy park.

A 10 MW(th) SLOWPOKE energy system is being developed by Atomic Energy of Canada Limited as a heat source specifically designed to satisfy the needs of local heating systems in building complexes, institutions and municipal district heating systems. Hot water at 85°C is provided for these purposes. A 2 MW(th) demonstration unit has been in operation since 1987 at the Whiteshell Laboratories in Manitoba.

In the Peoples' Republic of China, the HR-5 Nuclear Heating Test Reactor, developed by the Institute of Nuclear Energy (INET) in Beijing, is a 5 MW(th) water cooled reactor which began operation in 1989 and supplys hot water in the temperature range of 60 to 90°C to the INET centre. This reactor is establishing a technology base for possible future applications of nuclear district heat in China.

In the Russian Federation the AST light water cooled reactor has been designed specifically to provide hot water for district heating. Designs with power levels from 50 to 500 MW(th) have been developed.

Exploiting natural resources in the arid regions of West Kazachstan became possible once water and electricity supply problems were solved. An important contributor to this effort has been the Shevchenko complex. It includes a fast breeder reactor, type BN-350, three thermal power stations and a desalination plant with thermal distillation equipment. The complex constitutes the worlds first, and for the time being the only demonstration plant where a nuclear reactor is used in desalination of seawater.

As a nuclear heat source, the HTGR has the unique capability of providing temperatures up to 950 to 1000°C. In addition to the application of generating electricity by conventional steam turbine systems, the HTGR can provide helium gas at about 850°C for highly efficient gas turbine electric generating units, and up to 1000°C for high temperature process heat. Extensive research, development and demonstration programmes have been conducted on components and systems for application of nuclear process heat for the refinement and conversion of coal, oil and gas for the production of environmentally benign liquid energy carriers which can be used as fuel for transportation and heating. The advantages are the use of nuclear energy rather than fossil fuels for the process heat, reduction of problems with respect to the environment, particularly the reduction of problems of carbon dioxide. An important milestone in development of high temperature nuclear process heat was reached in March 1991 with the start of construction of the High Temperature Test Reactor (HTTR) at the Oarai Research Establishment of the Japanese Atomic Energy Research Institute. The HTTR will produce a core outlet temperature of 950°C and will be the first nuclear reactor in the world to be connected to a high temperature process heat utilization system.

3. THE ROLE OF THE IAEA IN ADVANCED REACTOR DEVELOPMENT
ROLE DE L'AIEA DANS LA MISE AU POINT DE REACTEURS AVANCES
EL ROL DEL OIEA EN EL DESARROLLO DE REACTORES AVANZADOS

The objectives of the next generation of nuclear plants include achievement of enhanced safety, increased reliability, greater public acceptability, improved economics, and their ultimate introduction throughout the world. The early development of nuclear power was conducted to a large extent on a national basis. However, for advanced reactors, international cooperation is playing a greater role, and the

Agency promotes technical information exchange and cooperation focused on these objectives. Especially for designs incorporating innovative features, international cooperation can play an important role allowing a pooling of resources and expertise in areas of common interest to help to meet the high cost of development.

3.1 Current IAEA Activities in Advanced Reactor Development
Activités actuelles de l'AIEA concernant la mise au point de réacteurs avancés
Actividades Actuales del OIEA en el Desarrollo de Reactores Avanzados

To support the IAEA's functions of encouraging development of atomic energy and fostering exchange of scientific and technical information for peaceful uses throughout the world, the IAEA's programme in nuclear power technology development promotes technical information exchange and cooperation between member states with major reactor development programmes, offers assistance to Member States with an interest in exploratory or research programmes, and publishes reports available to all Member States interested in the current status of reactor development.

The IAEA activities in development of water cooled, liquid metal cooled and gas-cooled reactors are coordinated by three International Working Groups (IWGs) which are committees of leaders of national programmes in these technologies. Each IWG meets periodically to serve as a global forum for information exchange and progress reports on the national programmes, to identify areas of common interest for collaboration and to advise the Agency on its technical programmes and activities. This regular review is conducted in an open forum in which operating experience and development programmes are frankly discussed.

The activities planned within the frame of these IWGs include technical information exchange meetings and cooperative Coordinated Research Programmes. Small Specialists Meetings are convened to review progress on selected technology areas in which there is a mutual interest. For more general participation, larger Technical Committee Meetings, Symposia or Workshops are held. The IWGs sometimes advise the Agency to establish cooperative programmes in areas of common interest in order to pool efforts on an international basis. These cooperative efforts are carried out through Coordinated Research Programmes (CRPs). CRPs are typically 3 to 5 years in duration and often involve experimental activities. Such CRPs allow a pooling of efforts on an international basis to develop technology for a lower cost than would be required with separate national efforts, and to benefit from the experience and expertise of researchers from the participating parties.

One example of a CRP is the international project underway at the PROTEUS critical experiment facility of the Paul Scherrer Institut (Villigen, Switzerland) where an international team has been assembled to plan, conduct and analyze a new series of critical experiments focused on the needs for validation data for HTGR designs being developed by the participating countries. Another example is the CRP on Acoustic Signal

Processing for the Detection of Sodium Boiling or Soidum/Water Reaction in LMFBRs which is examining experimental data and acoustic signal processing techniques to establish methods of detecting sodium boiling or sodium/water reactions rapidly and with high sensitivity.

Examples of recent Specialists and Technical Committee Meetings convened by the IAEA to promote information exchange are:

Advanced Water Cooled Reactors:
- Progress in Development and Design Aspects
- Cost Reduction Guidelines
- Structural Materials
- Nuclear Process Steam Applications

Liquid Metal Cooled Reactors:
- Steam Generator Failure and Failure Propogation
- Acoustic/Ultrasonic Detection of Sodium-Water Leaks in Steam Generators
- Instrumentation for Supervision of Core Cooling
- Advanced Controls for Fast Reactors

Gas-Cooled Reactors:
- Uncertainties in Core Physics Calculations
- Status of Graphite Development
- Fuel Behaviour during Accident Conditions
- Seismic Behaviour

Several forms of IAEA support are also available to Member States that do not have major reactor development programmes. Technical assistance is arranged for developing countries through the Agency for providing expert advice, training, fellowships and special equipment for research.

3.2 Future IAEA Activities in Advanced Reactor Development
Activités futures de l'AIEA concernant la mise au point de réacteurs avancés
Actividades Futuras del OIEA en el Desarrollo de Reactores Avanzados

Advanced reactors are considered by the Agency to have a high potential to contribute to the world's future energy generation. Further, one of the key elements of an interim response strategy to cope with the increasing risk of global warming and climate change is the future deployment of advanced nuclear power plants [7]. Therefore, the Agency intends to:

A) promote development of advanced nuclear power technologies focusing on the key issues (for example, safety concerns, high capital cost, complex and expensive operating procedures) which currently hinder introduction of nuclear power, and

B) assist developing countries to establish the expertise to be able to incorporate advanced reactor technologies into their power generation structure when these technologies are ready for introduction.

Therefore, Agency activities such as those described above which are conducted within the frame of the International Working Groups will continue, and in some cases should be intensified in order to promote development of advanced nuclear power technology. For example, new activities have been recommended by IWGs in areas such as international cooperation in planning and conducting experiments to validate predictions of the behaviour of advanced reactor designs which incorporate innovative, passive systems to ensure safety.

In further support of this Agency role of promoting development of advanced nuclear power, a key finding of the International Conference on the Safety of Nuclear Power convened in Vienna in September 1991 was that design features incorporated into advanced reactors should permit the technical demonstration of adequate public protection with significantly reduced emergency planning requirements: for example, relief from the requirement for rapid evacuation. Certainly this would have a positive influence on public acceptance of nuclear power, and it is recognized that improving public acceptance of nuclear power is very necessary if the potential offered by the next generation of nuclear power plants is to be realized. Activities which are currently underway and planned within the Agency's advanced nuclear power technology development programme include international information exchange and cooperation in the development of the detailed and proven knowledge of reactor physics and thermodynamic behaviour under off-normal and accident conditions. Such development is essential to the ultimate establishment of reactor designs which could result in reduced emergency planning requirements. The Agency also plans to organize a group of experts to establish in the long term safety criteria for the design of future reactors using a step by step approach which will begin with the development of safety principles.

Finally, Member States may find international cooperation in demonstration projects for first-of-a-kind plants to be desirable in view of their high cost and the shortage of financial resources in individual countries. In this case, if requested by the involved Member States, the Agency could play a role in assisting to establish and carry out such projects.

4. SUMMARY
RESUME
RESUMEN

Advanced nuclear power systems are currently under development with the potential to make a significant contribution to meeting the energy needs of the increasing world population in an environmentally acceptable manner. These systems can provide both the electric power demand and heat energy for district heating and industrial chemical processes. These systems are being developed to meet the challenges of increasingly demanding safety requirements, economical competitiveness and public acceptance.

Advanced reactors incorporating improvements demonstrated from the many reactor years of experience from the safety, reliability and economics point of view, should significantly reduce the probability of severe accidents and make them economically competitive with the best of clean fossil fuel electricity sources. There is no doubt that nuclear power is clean energy source both from the point of view of releasing climate changing atmospheric gases or from radioactive wastes. Regarding the latter, technology for the fixing relatively low volumes for disposal in geological formations is developed and is practically implementable. Conservation and energy efficiency alone, even if vigourously pursued, cannot yield all the increased requirements of mankind's energy resources. Amongst decision makers in most countries there is no doubt about the need for nuclear power, and in many countries, which need more electricity now, such views are being shared by an increasing number of members of the public. The better performance guarantees from advanced reactors from all points of view will help the process of acceptance from investors and the public alike and should result in a resurgence of nuclear power with the construction and operation of many advanced nuclear power plants in the future.

Because of the high cost of development of advanced reactors, especially the innovative concepts, Member States which have ongoing programmes in advanced reactor development are finding an advantage to cooperate internationally in technology development. The IAEA's programme in nuclear power technology encourages international cooperation through technical information exchange and coordination of research. To assure that the Agency's efforts are desirable and useful to Member States, the Agency's efforts in development of water cooled, liquid metal cooled and gas-cooled reactors are guided by three International Working Groups which are committees of leaders of the national programmes in each technology area. Cooperation conducted within the frame of these International Working groups allows a pooling of efforts in areas of common interest and benefits from the experience and expertise of researchers from the participating countries.

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SUMMARY

Advanced nuclear power systems are currently under development with the potential to make a significant contribution to meeting the energy needs of the increasing world population in an environmentally acceptable manner. These systems can provide both the electric power demand and heat energy for district heating and industrial chemical processes. These systems are being developed to meet the challenges of increasingly demanding safety requirements, economical competitiveness and public acceptance.

Advanced reactors incorporating improvements demonstrated from the many reactor years of experience from the safety, reliability and economics point of view, should significantly reduce the probability of severe accidents and make them economically competitive with the best of clean fossil fuel electricity sources. There is no doubt that nuclear power is clean energy source both from the point of view of releasing climate changing atmospheric gases or from radioactive wastes. Regarding the latter, technology for the fixing relatively low volumes for disposal in geological formations is developed and is practically implementable. Conservation and energy efficiency alone, even if vigourously pursued, cannot yield all the increased requirements of mankind's energy resources. Amongst decision makers in most countries there is no doubt about the need for nuclear power, and in many countries, which need more electricity now, such views are being shared by an increasing number of members of the public. The better performance guarantees from advanced reactors from all points of view will help the process of acceptance from investors and the public alike and should result in a resurgence of nuclear power with the construction and operation of many advanced nuclear power plants in the future.

Because of the high cost of development of advanced reactors, especially the innovative concepts, Member States which have ongoing programmes in advanced reactor development are finding an advantage to cooperate internationally in technology development. The IAEA's programme in nuclear power technology encourages international cooperation through technical information exchange and coordination of research. To assure that the Agency's efforts are desirable and useful to Member States, the Agency's efforts in development of water cooled, liquid metal cooled and gas-cooled reactors are guided by three International Working Groups which are committees of leaders of the national programmes in each technology area. Cooperation conducted within the frame of these International Working groups allows a pooling of efforts in areas of common interest and benefits from the experience and expertise of researchers from the participating countries.

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