Global development of advanced nuclear power plants, and related IAEA activities

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FOREWORD

Renewed interest in the potential of nuclear energy to contribute to a sustainable worldwide energy mix is underlining the IAEA's statutory role in fostering the peaceful uses of nuclear energy, in particular the need for effective exchanges of information and collaborative research and technology development among Member States on advanced nuclear power technologies deployable in the near term as well as in the longer term. For applications in the medium to longer term, with rising expectations for the role of nuclear energy in the future, technological innovation has become a strong focus of nuclear power technology developments by many Member States.

To meet Member States' needs, the IAEA conducts activities to foster information exchange and collaborative research and development in the area of advanced nuclear reactor technologies. These activities include coordination of collaborative research, organization of international information exchange, and analyses of globally available technical data and results, with a focus on reducing nuclear power plant capital costs and construction periods while further improving performance, safety and proliferation resistance. In other activities, evolutionary and innovative advances are catalyzed for all reactor lines such as advanced water cooled reactors, high temperature gas cooled reactors, liquid metal cooled reactors and accelerator driven systems, including small and medium sized reactors. In addition, there are activities related to other applications of nuclear energy such as seawater desalination, hydrogen production, and other process heat applications.

This brochure summarizes the worldwide status and the activities related to advanced nuclear power technology development and related IAEA activities. It includes a list of the collaborative research and development projects conducted by the IAEA, as well as of the status reports and other publications produced.

CONTENTS

Introduction

Nuclear energy, which has demonstrated an excellent technical and economic performance in many countries, has played an important role in the global energy supply since its commercial introduction about three decades ago. There were 443 nuclear power reactors in operation in 31 countries by mid-2006. These reactors provided a total of about 370 gigawatts electricity generating capacity, representing about 16% of the world's total electricity generating capacity. After two decades of relatively slow development before the turn to the 21st century, recently there has been resurging interest in the deployment of nuclear energy. The constructions of nuclear power reactors this time, unlike before, are concentrated in developing countries, particularly China and India. Currently, sixteen of the twenty-six new reactors under construction are in developing countries. In many developing countries, the need for nuclear power is driven by national strategies focused on long term energy supply. In developed countries, the driving forces behind the renewed interest in nuclear power are mainly environmental concerns related to fossil-burning, and security of global energy supply. Hence, in recent years, the projections for the growth of nuclear power generation have become more optimistic. One of IAEA's projections predicts that global nuclear power capacity will grow by an average of about 2% per year to reach 640 gigawatts electric by 2030 – an increase by almost 75% compared to 2006.

The IAEA's Statute includes the following functions: Article III-A.1: "To encourage and assist research on, and development and practical application of, atomic energy for peaceful uses throughout the world;" Article III-A.3: "To foster the exchange of scientific and technical information on peaceful uses of atomic energy."

Today, global environmental change, and the continuing increase in global energy supply required to provide increasing populations with an improving standard of living, make these functions, first implemented when the Statute came into force in 1957, even more relevant.

The renaissance of nuclear energy has emphasized the necessity for immediate and effective exchange of information among Member States on improvement of existing nuclear power technologies as well as new nuclear power technologies deployable in the near term. With rising expectations for the role of nuclear energy in a longer future, technological innovation has also become a strong focus of nuclear power technology developments by many Member States. There is a general consensus within the nuclear industry that the development of new technologies should be conducted in a sustainable manner, while meeting the increasing energy demands of the 21st century. To meet these needs, as required by the Member States, IAEA has several activities to foster information exchange and collaborative research and development in the area of advanced nuclear reactor technologies.

The organization and execution of these activities are governed by the Statute of the IAEA, which stipulates, among others, that the IAEA shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world; and that the IAEA is authorized to encourage and assist research on, and development and practical applications of atomic energy for peaceful uses. In these activities, IAEA staff coordinates cooperative research, organizes international information exchange, and analyses globally available technical data and results, with a focus on reducing capital costs and construction periods while further improving performance, safety and proliferation resistance. Evolutionary and innovative advances are catalyzed for all reactor lines (advanced water cooled reactors, high temperature gas cooled reactors, liquid metal cooled reactors and accelerator driven systems) including small and medium sized reactors. Non-electricity generation applications such as seawater desalination, process heat and hydrogen generation are also important components of the activities.

Organization of activities

The IAEA periodically informs its Board of Governors and General Conference on the status of its programmes, and incorporates feedback from them into the programmes. To ensure that work fully reflects the interests of Member States, the Department of Nuclear Energy has established working groups in relevant areas of the IAEA's activities under its responsibilities. In the area of nuclear power technology development, technical working groups (TWGs) for each major reactor type and the International Nuclear Desalination Advisory Group (INDAG) have been established.

The TWGs and INDAG are standing technical groups with members who are leading representatives of national programmes. Most of the members are from governmental organizations and all are nominated by their governments, thus providing review and guidance directly from Member States. Other international organizations, such as the European Commission and the OECD Nuclear Energy Agency, are also invited to send representatives to facilitate coordination with their programmes.

The standing technical working groups meet every one to two years and provide recommendations on formulating the IAEA's activities. At the meetings, members review and discuss national development programmes, progress of activities, key issues, and proposals for future activities. Recommendations are made for activities to be incorporated in the IAEA's programme and budget. Following IAEA approval, the activities are implemented with the support of the TWGs.

The scope of the nuclear power technology development TWGs is broad, integrating the application of advanced technologies in all aspects of reactor development, deployment and operation. Some specific topics are addressed in more depth in other international organizations and in different sections of the IAEA, for example within the framework of the TWG on Nuclear Power Plant Control and Instrumentation, the TWG on Water Reactor Fuel Performance and Technology, and the TWG on Life Management of Nuclear Power Plants. It is ensured that all IAEA programmes and activities are well coordinated, and any unproductive overlap within the IAEA and with other international organizations is avoided.

An important initiative of the IAEA on nuclear power innovation launched by the GC 2000 is the "International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)", which was established mainly to ensure that nuclear energy is available to contribute, in a sustainable manner, to energy needs in the 21st century. INPRO provides a forum for discussion and is developing a methodology for assessment of innovative nuclear systems.

At the IAEA, the activities related to advanced nuclear power technology development are conducted by established mechanisms. Topical technical meetings are convened to review progress on selected technology areas in which there is a specific interest among a number of Member States. For topics of broader interest, symposia or conferences are generally organized. Collaborative research is performed through coordinated research projects (CRPs) that are typically 3 to 5 years in duration and often involve experimental activities. When it is beneficial to its programmes and of interest to Member States, IAEA staff also participates in international meetings and cooperation organized by other organizations and institutions.

The IAEA publishes status reports that provide balanced and objective information about the state-of-the-art, recent results achieved in nuclear power technology development programmes in Member States and trends for current and future reactor systems and their applications. These reports help Member States considering implementation of nuclear power programmes, as well as those with existing programmes, to maintain current awareness of advances in technology development throughout the world.

The following sections summarize the status of IAEA activities related to advanced nuclear power technology development. A list of currently active CRPs, status reports and publications issued since 1995 is given at the end of this brochure.

SMALL AND MEDIUM SIZED REACTORS[1]

In operation[2]	138
Under construction	9
Number of countries with SMRs	28
Generating capacity, GW(e)	63.4
Operating experience, reactor-years	5526

There is a renewed interest in Member States in the development and application of small and medium sized reactors (SMRs). In the near term, most new NPPs are likely to be evolutionary designs building on proven systems while incorporating technological advances and often the economies of scale, resulting from the reactor outputs of up to 1600 MW(e). For the longer term, the focus is on innovative designs aiming to provide increased benefits in the areas of safety and security, non-proliferation, waste management, resource utilization and economy, as well as to offer a variety of energy products and flexibility in design, siting and fuel cycle options. Many innovative designs are reactors within the small-to-medium size range, having an equivalent electric power less than 700 MW(e) or even less than 300 MW(e).

A general consideration for having small and medium sized reactors (SMRs) in nuclear power's portfolio is that 'one-size' approach is unlikely to fit for all, like it doesn't in other major industries, including car and aircraft industry, as well as energy production from fossil fuel. However, the stagnation period that followed the Chernobyl accident, the liberalization of energy markets, and the progress in certain technologies of energy production from fossil fuel, combined until recently with relatively low prices for natural gas and oil, altogether forced nuclear industries to fight for survival rather than to consider expansion, making the construction of any single new nuclear power plant a self-standing priority. Such situation, predominant over the past two decades, was generally unfavourable to many older SMR designs, especially those that just reproduced the features of higher-capacity reactors at a reduced scale. As a result, older SMRs failed to compete with larger plants on an economy of scale basis, resulting in a loss of interest from many major vendors and utilities.

On the other hand, the above mentioned developments boosted SMR designers all over the world to pursue new design approaches making use of certain advantages provided by a smaller reactor size to achieve reduced

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[1] According to the classification adopted by the IAEA, small reactors are reactors with the equivalent electric power less than 300 MW, medium sized reactors are reactors with the equivalent electric power between 300 and 700 MW.

[2] Reactor data presented in this publication are results as of June 2006 and are derived from the IAEA's Power Reactor Information System.

design complexity and, perhaps, simplified operation and maintenance requirements. In most cases, the design approaches used for these SMRs are unique, i.e. cannot be reproduced in the reactors of a larger capacity and, therefore, represent alternative strategies to overcome loss of the economies of scale.

Through incorporating more inherent and passive safety features in their original concepts, the designers of many innovative SMRs target the reduction or elimination of an emergency planning zone, which would enhance the flexibility in siting and applications of nuclear power plants (NPPs) with such reactors.

Most innovative SMR designs provide for multiple and flexible cogeneration options, ranging from district heating and potable water co-production to several advanced process heat applications, which could potentially ensure higher economic competitiveness of a plant, especially if the plant is located in the proximity to the customer.

Applying design approaches unique to SMRs is one distinct strategy to overcome loss of the economies of scale; another approach being examined by many innovative SMR designers is related to an option of incremental capacity increase based on staggered build of multiple reactor modules. With the latter approach, the overall achieved capacity of an NPP may be even higher than in single-unit high capacity plants, while the necessary capital investments would be spread over time, taking a benefit of the discount rate and the effect of learning, while minimizing the investment risk.

As of 2006, more that 56 concepts and designs of innovative SMRs are being analysed or developed within national and international programmes in 13 IAEA Member States, including both industrialized and developing countries. Innovative SMRs are under development for all principle reactor lines, i.e. water cooled, liquid metal cooled, gas cooled, molten salt cooled and some unusual combinations thereof. The projected timelines of readiness for deployment are generally between 2010 and 2030.

Of these innovative SMRs, the SMART-P (Republic of Korea) and a floating NPP with the KLT-40S (Russian Federation) are scheduled for construction startup in 2006; the PBMR (South Africa) is to be started in construction in 2007. All three have a potential to be deployed by 2010-2011; and there are several more designs that could be deployed either as prototypes or as first-of-a-kind plants within the next decade.

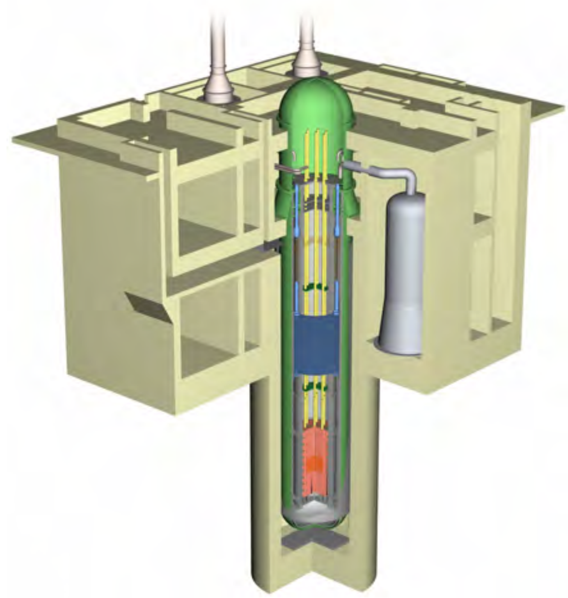
Competitiveness of SMRs depends on the incorporated strategies to overcome loss of the economies of scale but equally it depends on finding appropriate market niches for such reactors, complete with the elaboration of market penetration strategies.

The attractive features of innovative SMRs that might facilitate their penetration to certain energy markets are as follows:

- Fitness for small electricity grids, including autonomous operation;
- Reduced design complexity, reduced impact of human factors, and, perhaps, reduced infrastructure and staff requirements, which could make the corresponding designs a good choice for many developing countries;
- Lower absolute overnight capital costs, as compared to large capacity plants;
- An option of incremental capacity increase that could perfectly meet the incremental increase of demand and minimize financial risk to an investor;
- For some designs, an option of operation without on-site refuelling that could result in reduced obligations of the user for spent fuel and waste management and could also provide possibly greater or easier non-proliferation assurances to the international community; and, last but not least
- SMRs are a preferred option for those non-electric applications that require a proximity to the customer, such as seawater desalination, district heating, and certain process heat applications.

Reflecting on the developments in Member States, the IAEA carries out a dedicated project, which has as objective to ensure progress in the development of advanced technologies and in definition of enabling infrastructure issues common to SMRs of various types.

The activities include coordinated research projects (CRPs) on important topics of design and technology development and assessment of various SMR options, preparation of status reports of innovative SMR designs, preparation of topical reports on important common issues for SMRs such as competitiveness and passive safety design options, organization of workshops on deployment and application potential of SMRs of certain lines, and provision of support to the Technical Cooperation programme.



General view of a small lead-bismuth cooled reactor — a concept of a small reactor without on-site refuelling developed by Japan Atomic Energy Agency (JAEA)

Website of the CRP "Small reactors without on-site refuelling": http://www.iaea.org/OurWork/ST/NE/NENP/NPTDS/Projects/SMR/SMR_CRP1_SRWOSR/index.html

Website of the project "Common technologies and issues for SMRs": http://www.iaea.org/OurWork/ST/NE/NENP/NPTDS/Projects/SMR/index.html

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GAS COOLED REACTORS

Worldwide, there are currently 22 gas cooled reactor (GCR) plants supplying energy for the generation of electricity, cooled by carbon dioxide and 2 test reactors of the helium cooled type. Current international interest in modular high temperature gas cooled reactor (HTGR), designs, and their promising safety and economic features, forms the basis for Member States' participation in the IAEA's GCR activities.

Power reactors in operation	22
Under construction	0
Test reactors in operation	2
Number of countries with GCRs	3
Generating capacity, GW(e)	10.7
Operating experience, reactor-years	1591

Several Member States have research and development programmes related to the application of the HTGR as an advanced nuclear energy source for the future. Primary objectives of these programmes are the generation of electricity, via the direct or indirect coupling of a gas turbine to an HTGR, resulting in a net plant efficiency of 40-50%. In addition to electricity generation, HTGR designs are also well placed for co-generation of process heat, promising high thermal efficiency. Potential process heat applications include high-temperature applications such as hydrogen production and low temperature applications, such as seawater desalination and district heating.

At the IAEA activity level, major gas cooled reactor activities are conducted with input and advice from the Technical Working Group on Gas Cooled Reactors (TWG-GCR), and are directed towards the exchange of scientific and technical information between Member States to minimize design uncertainties and optimise inherent safety features. Current activities include three major coordinated research projects (CRPs), CRP-5 on HTGR performance evaluation, which focuses on core physics and thermal-hydraulics benchmarking, CRP-6 which focuses on advances in HTGR fuel technology and a new CRP, CRP-7, which addresses the potential of HTGRs for process heat applications, including hydrogen production and seawater desalination. In addition, conferences, topical meetings, and training workshops are organized periodically to facilitate information exchange.

JAEA's high temperature engineering test reactor has the capability to operate at a core outlet temperature of 950°C and is utilized to investigate technologies for advanced HTGRs, to demonstrate nuclear process heat applications, and to serve as an irradiation test facility for high temperature research activities *(Courtesy of Japan Atomic Energy Agency)*

Members of the TWG-GCR, established in 1978

China	Republic of Korea
France	Netherlands
Germany	Russian Federation
Indonesia	South Africa
Japan	Turkey
USA	United Kingdom

At the international level, HTGR-related R&D projects are under way in several Member States, including South Africa, China, Japan, Russian Federation, USA, countries of the European Union, and the Republic of Korea.

In South Africa, PBMR (Pty) Ltd is accelerating its efforts on licensing work on a 165 MW(e) pebble bed modular reactor (PBMR), which is expected to be commissioned around 2010. The South African Government has already allocated initial funding for the project and orders for some lead components have already been made.

In China, work continues on safety tests and design improvements for the 10 MW(th) high temperature gas cooled reactor (HTR-10) and plans are also in place for the design and construction of a power reactor prototype (HTR-PM).

In Japan, a 30 MW(th) high temperature engineering test reactor (HTTR) began operation in 1998 and work continues on safety testing and coupling to a hydrogen production unit. A 300 MW power reactor prototype is also under consideration.

The Russian Federation, in cooperation with the USA, continues its research and development work on a

284 MW(e) gas turbine modular helium reactor (GT-MHR) for plutonium burning.

France has an active R&D programme on both thermal as well as fast gas reactor concepts and in the USA, efforts by the Department of Energy (DOE) continue on the qualification of advanced gas reactor fuel, with work being performed at major labs such as the Idaho National Laboratory and Oak Ridge.

Website: www.iaea.org/htgr

IAEA contact for GCRs: M.Methnani@iaea.org

ADVANCED TECHNOLOGIES FOR WATER COOLED REACTORS

Investments are being made in many Member States for developing advanced technologies for water cooled reactors, which comprise the large majority of the world's reactors. This project fosters the global realization and sharing of the benefits of resulting technology advances by facilitating international information exchange and cooperation. The activities are formulated on the advice, and are carried out with the support, of the Technical Working Groups for Advanced Technologies for Light Water Reactors and Heavy Water Reactors (the TWG-LWR and the TWG-HWR).

Members of the TWG-LWR, established in 1987

Argentina	India	Switzerland
Belgium	Italy	United Kingdom
China	Japan	USA
Czech Republic	Republic of Korea	OECD-NEA
Finland	Russian Federation	European Commission
France	Spain	
Germany	Sweden	

Members of the TWG-HWR, established in 1997

Argentina	Republic of Korea
Canada	Pakistan
China	Romania
India	Russian Federation

Current activities focus on approaches for improving economic competitiveness while maintaining high levels of safety. To gain the maximum improvements in economics, proven means for reducing costs must be fully utilized, and new approaches should be developed and implemented. Proven means and new approaches are examined using the full breadth, expertise and capabilities of several divisions of the IAEA.

The scopes of the TWG-LWR and the TWG-HWR are quite broad, covering technology improvements for current plants and development of new designs. For the TWG-LWR, this includes specifically the reactor core, plant systems and components, structures and containment, as well as technologies for improved operation and maintenance. The TWG-HWR activities emphasize anticipated future developments in HWRs, covering safety, economics and fuel resource sustainability. Activities on technology areas of common interest to these two TWGs are conducted jointly.

Some specific technology areas are addressed in more depth within the IAEA (e.g. the TWG-NPPCI, the TWG-FPT, and the TWG-LMNPP), and by other international organizations (e.g. the OECD-NEA). The TWG-LWR and the TWG-HWR keep abreast of such work and coordinate their activities with the activities of these other groups.

The detailed results of recent activities for water cooled reactor project are available over the Internet at http://www.iaea.org/OurWork/ST/NE/NENP/NPTDS/Projects/hlwr.html

Some recent activities include coordinated research projects (CRPs) on "Thermohydraulic relationships for advanced water cooled reactors" and on "Thermophysical properties of materials of LWRs and HWRs". These efforts provide improved data bases for use in calculational tools and should help to realize more economic designs for future reactors by removing the need to incorporate excessively large margins into the designs simply for the purpose of allowing for large uncertainties in data.

A CRP is currently under way on "Natural circulation phenomena, modeling and reliability of passive systems that utilize natural circulation". The CRP aims at improving the understanding of natural circulation phenomena in advanced designs and passive safety systems.

Other activities have included information exchange on technologies for improving performance of current and future water cooled reactors, reviewing recent experience with proven means for reducing costs of new plants, and identified new approaches for reducing costs of future plants.

Light water reactors (LWRs) are dominating among the operating nuclear power plants throughout the world, both in number and total power. The current LWR technologies have proven to be economic, safe and reliable, and they have a mature infrastructure and regulatory base in several countries.

Light water reactors

In operation	361
Under construction	19
Number of countries with LWRs	27
Generating capacity, GW(e)	326.4
Operating Experience, reactor years	8983

Tokyo Electric Power Company's Kashiwazaki-Kariwa Units 6&7 advanced BWRs, which started commercial operation in November 1996 and July 1997 respectively. These plants were constructed by an international joint venture consisting of General Electric Nuclear Energy (USA), and Hitachi, Ltd, and Toshiba Corporation. (Japan) ***(Credit: TEPCO)***

Some examples of development activities for new, advanced LWR designs are given below:

In France and Germany, Framatome ANP has developed the large-size European Pressurized Water Reactor (EPR), which meets European utility requirements. The EPR's higher power level relative to the latest series of PWRs operating in France (the N4 series) and Germany (the Konvoi series) has been selected to capture economies of scale.

Construction of the EPR in Finland — positioning of the bottom part of the metallic liner on the base slab (May 2006) ***(Credit: Framatome ANP)***

In December 2003, Teollisuuden Voima Oy (TVO) of Finland signed a turnkey contract with Framatome ANP and Siemens AG for an EPR for the Olkiluoto site. Commercial operation is planned for mid-2009. Also, Electricité de France is planning to construct an EPR at Flamanville (Unit 3). Framatome has received design approval for the EPR from the French Safety Authority in October 2004. Start of construction is projected for 2007 with grid connection in 2012.

In Germany, Framatome ANP with international partners from Finland, Netherlands, Switzerland and France is developing the basic design of the SWR-1000, an advanced BWR with passive safety features.

In Japan, benefits of standardization and construction in series are being realized with the ABWR units. The first two ABWRs in Japan, the 1356 MW(e) Kashiwazaki-Kariwa 6 and 7 Units, have been in commercial operation since 1996 and 1997 respectively. The ABWR, Hamaoka Unit 5, began commercial operation in January 2005, and the ABWR Shika Unit 2 began commercial operation in March 2006. Deployment programmes are under way for 8 more ABWRs. Two ABWRs are under construction in Taiwan, China.

Expectations in Japan are that future ABWRs will achieve a significant reduction in generation cost relative to the first ABWRs. The means for achieving this cost reduction include standardization, design changes and improvement of project management, with all areas building on the experience of the ABWRs currently in operation. In addition, a development programme was started in 1991 for ABWR-II, aiming to further improve and evolve the ABWR, with the goal of significant reduction in power generation costs relative to a standardized ABWR. The power level of ABWR-II has been increased relative to the ABWR, and benefits of economies of scale are expected.

Commissioning of the first ABWR-II is foreseen in the late 2010s. Also in Japan, the basic design of a large advanced PWR has been completed by Mitsubishi Heavy Industries and Westinghouse for the Japan Atomic Power Company's Tsuruga 3 and 4 Units, and a larger version, the APWR+ is in the design stage.

In the Republic of Korea, the benefits of standardization and construction in series are being realized with the Korean Standardized Nuclear Plant (KNSP) series. Eight KNSPs are in commercial operation. The accumulated experience is now being used by Korea Hydro and Nuclear Power (KHNP) to develop the improved KSNP named the Optimized Power Reactor (OPR), with the first units planned for Shin-Kori Units 1 and 2 with commercial operation planned for 2010 and 2011, respectively. In addition, the development of the Korean Next Generation Reactor, now named the Advanced Power Reactor 1400 (APR-1400), was started in 1992, building on the experience of the KSNPs. The higher power level of the APR-1400 relative to the KSNP and the OPR has been selected to capture economies of scale. Recent development of the APR-1400 focused on improving availability and reducing costs. In March 2001, KHNP started the Shin-kori 3, 4 project for the APR1400, with completion scheduled for 2013 and 2014.

In the USA, designs for a large sized advanced PWR (the Combustion Engineering System 80+) and a large sized BWR (General Electric's ABWR) were certified in May 1997. Westinghouse's mid-size AP-600 design with passive safety systems was certified in December 1999. Westinghouse has developed the AP-1000 applying the passive safety technology developed for the AP-600 with the goal of reducing the capital costs through economies of scale. Westinghouse received design certification from the U.S.NRC in February 2006. A Westinghouse led international team is developing the modular, integral IRIS design in the small to medium-size range, with a core design capable of operating on a 4-year fuel cycle[3]. The IRIS design is in pre-application review during which the NRC will provide feedback on necessary testing and an assessment of the risk-informed regulation approach. Design certification for IRIS is targeted for 2008-2010. General Electric is designing a large ESBWR applying economies of scale together with modular passive safety systems. The design draws on technology features from General Electric's ABWR and from their earlier mid-size simplified BWR with passive systems. The ESBWR is in the design certification review phase with the U.S.NRC.

The U.S. Department of Energy's Nuclear Power 2010 programme, together with industry, is funding development of three early site permits and work toward preparation of three combined construction permit and operating license applications (COL) with the U.S.NRC. The COL process is a "one-step" process by which safety concerns are resolved prior to start of construction, and NRC issues a license for construction and operation of a new plant.

In the Russian Federation, efforts continue on evolutionary versions of the currently operating WWER-1000 (V-320) plants. This includes the WWER-1000 (V-392) design, of which two units are planned at the Novovoronezh site, and WWER-1000 units under construction in China, India and the Islamic Republic of Iran. Development of a larger WWER-1500 design has been initiated.

In China, the China National Nuclear Corporation (CNNC) has developed the AC-600 design, and is currently developing the CNP-1000 for electricity production. CNNC is also developing the QS-600 e/w, which is based on the design of the Qinshan Phase II, for electricity production and seawater desalination. China is pursuing self-reliance both in designing the plant to meet Chinese safety requirements, and in fostering local equipment manufacture with the objective of reducing construction and operation costs. Experience gained and lessons learned from the design, construction and operation of the Qinshan and Daya Bay NPPs are being incorporated.

Several countries are developing innovative LWR designs, which represent a greater departure from current systems, and may require a prototype or demonstration plant as part of the development programme. Innovative LWR designs include some integral designs in which the reactor core and steam generator are housed in the same pressure vessel, and designs with tight fuel lattices for achieving a high fissile conversion ratio.

Generation IV is developing innovative, super-critical water cooled reactors. These designs would operate thermodynamically in the supercritical regime (above 22.4 MPa and 374 ºC), and would achieve a higher thermal efficiency than current water cooled reactors.

An IAEA TECDOC on Status of advanced LWR designs: 2004, has recently been published.

Heavy water moderated reactors

In operation	46
Under construction	6
Number of countries with HWRs	7
Generating capacity, GW(e)	24.0
Operating experience, reactor years	941

Heavy water reactors are a significant proportion of world reactor installations. They provide fuel cycle flexibility for the future and can potentially burn the spent fuel from LWRs, with no major reactor design changes, thus extending resources and reducing spent fuel arising.

Most of the members of the TWG-HWR are from developing countries, which have HWRs in their nuclear power programmes. The IAEA's technical aid and initiative via TWG-HWR activities are therefore especially important in assisting these countries.

[3] IRIS is considered to be an evolutionary LWR in IAEA terminology (for terminology, see IAEA-TECDOC-936). The integral design of IRIS represents a radical change in system configuration from existing loop reactors.

In China, the Qinshan CANDU project, a partnership between AECL, Canada and the Third Qinshan Nuclear Power Company (TQNPC) for two 700 MW(e) CANDU-6 units has resulted in commercial operation of Qinshan Unit 1 in December 2002, after a 54 month construction period. Unit 2 went into service in July 2003.

Tarapur 3 and 4, India *(Credit NPCIL)*

New HWR designs are being developed mainly in Canada and India.

In Canada, AECL is adapting the basic CANDU design to develop the Advanced CANDU Reactor (ACR), focusing on improvements in economics, inherent safety characteristics and performance, while retaining the features of the earlier family of HWR nuclear power plants. The basic concept is suitable for a range of plant sizes with electrical outputs in the range of 400 MW(e) to 1200 MW(e). The design is optimized by utilizing SEU fuel to reduce the reactor core size, which reduces the amount of heavy water required to moderate the reactor and allows the use of light water coolant.

AECL also has a research and development programme on innovative plants (CANDU-X) operating at higher thermal efficiencies, with high temperature coolant or supercritical water as coolant. Such reactors would also incorporate passive natural circulation heat removal wherever possible, and passive containment heat removal.

In India, a process of evolution of HWR design has been carried out since the Rajasthan 1 and 2 projects. India's 540 MW(e) HWR design incorporates feedback from the indigenously designed 220 MW(e) units, and in June 2005 the first of two 540 MW(e) units at Tarapur was connected to the grid. India is also designing an evolutionary 700 MW(e) HWR, and is developing the Advanced Heavy Water Reactor (AHWR), a heavy water moderated, boiling light water cooled, vertical pressure tube type reactor, optimized for utilization of thorium for power generation, with passive safety systems.

An IAEA CRP on "Intercomparison of techniques for pressure tube inspection and diagnostics" is nearing completion, and an international standard problem exercise on "Intercomparison and validation of computer codes for HWR thermalhydraulics safety analysis" has recently been completed.

Technical Reports Series No. 407 on "Heavy Water Reactors, Status and Projected Developments" presenting the status of HWR advanced technology in the areas of fuel cycle flexibility and sustainable development, safety and economics, and the advanced technology developments needed in the future, was published in 2002.

Website for LWRs and HWRs:
http://www.iaea.org/OurWork/ST/NE/NENP/NPTDS/Projects/hlwr.html

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FAST REACTORS

Energy production with fuel breeding is the main goal of fast reactor (FR) development to ensure long term fuel supply. Fast reactors are also being investigated to reduce the actinide content of nuclear waste, and to take advantage of their high thermal efficiency. Sodium cooled fast reactors have been operating successfully in several countries to produce energy and to demonstrate the first nuclear power plant for seawater desalination in the world (BN-350 in Kazakhstan, which was commissioned in 1964, generated first electricity in 1973, and was shut down in 1998).

In China, the 65 MW(th) [25 MW(e)], sodium cooled, pool type China Experimental Fast Reactor (CEFR) is under construction, as the first step in the Chinese FR development. About 80% of the non-sodium, and 30% of the sodium systems have been installed. Main vessel installation was started in August 2005 and is nearing completion. The installation of all systems below +16.8 m main building level will be completed by the end of 2006, along with the common island and most of the auxiliary systems. Commissioning and pre-operation testing of some auxiliary systems (e.g. water desalination, sodium acceptance system, etc.) is under way. Eighty-five tonnes of reactor grade sodium was transferred to the site and stored in storage tanks. First criticality is foreseen for mid-2009, and grid connection in mid-2010. The next two stages in the Chinese FR technology development are centred on the 600 MW(e) Prototype Fast Reactor (CPFR), for which design work has started in 2005, and on the 1000-1500 MW(e) Demonstration Fast Reactor (CDFR), respectively. The role of the FR with regard to minor actinide transmutation is also being evaluated taking as reference the CPFR.

Liquid metal fast reactors

In operation	3
Under construction	1
Number of countries with FRs	4
Generating capacity, GW(e)	1.04
Operating experience, reactor years	171

In France, decommissioning work that started in 1999 is under way at the Superphénix FR. The last fuel subassembly was unloaded on 19 March 2003. A total of 650 subassemblies have been successfully transferred, washed and stored in the water pool. Unloading of steel and shielding subassemblies is under way and will be completed by the end of 2006. By the end of 2005, about 50 small primary components have been treated (dismantled and cleaned in special cleaning pits). For large components, a special cutting workshop will be built in the reactor building, and the dismantling and treatment of the 4 coolant pumps and 8 intermediate heat exchangers is planned to start in 2007. In 2004, all the turbine hall components were dismantled. As for Phénix, the annual availability factor in 2005 was 85%, close to historical records. The reactor will be operated for 4 additional irradiation cycles of 100 EFPD each, adding up to approximately 3½ years of operation, and leading to a final shutdown of the plant in 2009. The objectives of the remaining experimental programme at Phénix are twofold: to perform the irradiation tests in support of the CEA transmutation R&D programme in the framework of the 30 December 1991 law on long-lived radioactive waste management, and to support research on future innovative designs. With respect to R&D, the French innovative nuclear systems programme focuses on the development of fast neutron spectrum systems with a closed fuel cycle in response to sustainability requirements, and on the development of key technologies for nuclear hydrogen production. For fast neutron spectrum reactors with a closed fuel cycle, CEA is implementing a dual strategy that pursues, within the frame of the Generation IV International Forum collaboration, R&D on innovative sodium cooled FRs, as well as in-depth R&D on the critical aspects of the gas cooled FR concept. For the former, it is planned to commission a 250-600 MW(e) prototype sodium cooled FR around 2020, aiming at demonstrating improved economics and enhanced safety characteristics of its innovative design features. For the latter, it is planned to have an experimental gas cooled FR in the 50 MW(th) range operational around 2017, aiming at demonstrating the viability of the key technological choices of such a concept.

In India, the Fast Breeder Test Reactor (FBTR) was in operation up to a power level of 17.4 MW(th). The peak burnup achieved in the MK-1 carbide fuel is 154.4 GWd/t without failure. The Prototype Fast Breeder Reactor (PFBR) mixed uranium-plutonium oxide test fuel subassembly has achieved a peak burnup of 59.8 GWd/t. There was no incident of sodium leak or leak in the steam generator. As for the 500 MW(e) PFBR, the detailed design has been completed for almost all the major components. PFBR is now under construction at Kalpakkam. The Preliminary Safety Analysis Report (PSAR) has been revised incorporating the comments of safety committees. A document has been prepared consolidating the R&D activities of PFBR. Manufacturing of long delivery mechanical components including the main vessel, sodium pumps and steam generators is in progress. The construction of PFBR is progressing well to respect the schedule date of commissioning by September 2010. Fast reactor related R&D works in the field of component development, thermal hydraulics, structural mechanics, materials and metallurgy, safety, fuel chemistry and reprocessing are progressing. Preliminary activities are also in progress towards design of future fast breeder reactors with improved economy and enhanced safety.

Prototype fast breeder reactor (PFBR): Reactor vault base preparation (*Credit: IGCAR*)

In Japan, the direction of the R&D efforts in the field of fast breeder reactor cycle technology is determined, apart from the constant pursuit of further safety enhancements, to a large extent by the goal of economic efficiency at the commercialization stage of this technology (the goal is economic efficiency comparable to that of the LWR technology). The first phase of the "Feasibility study on commercialized fast reactor cycle systems" was completed in March 2001. The three-year period extending over the fiscal years 2001 through 2003 constituted the initial term of the second phase, in which R&D activities focused on the design of the concepts and on the testing of key technologies. The interim summary report was reviewed by the Japanese Government at the end of 2003 and beginning of 2004. The final report after the second phase, based on the results of the studies performed over the five-year period 2001-2005, was compiled in 2005, and is currently under "check and review" by the Government. The objective of this report is to "identify the most promising candidate concept for the commercialization of the FR cycle, as well as to draw up the future R&D programme." The outcomes of the second phase include also a "principle for prioritizing R&D as well as R&D programmes until approximately 2015, and the potential future issues." Subsequently, a flexible and strategic R&D plan for those concepts will be developed toward the commercialization of the FR cycle system. In February 2005, the Governor of the Fukui province granted preliminary permission for plant modification work in view of the restart of the 280 MW(e) prototype fast breeder reactor MONJU, which had been shut down since December 1995 after a sodium leakage accident in the secondary heat transport system during the 40% power pre-operational testing phase. Japan Nuclear Cycle Development Institute (JNC), now Japan Atomic Energy Agency (JAEA) has immediately started preparatory work for modification, and the main modification work is in progress since September 2005. By the end of April 2006, these works have achieved 63% completion. The experimental fast reactor JOYO has successfully completed and tested the plant and core modifications for the MK-III upgrade programme (increase of the neutron flux, increase of the reactor availability, upgrading of the irradiation testing capabilities), and rated power operation [140 MW(th)] started in May 2004. By now, the 2nd MK-III cycle was completed. Within the framework of JOYO's programme for the development of advanced fuels and materials, as well as of minor actinide burning and transmutation technology, it is planned to start irradiation, from the 3rd MK-III cycle on, of oxide dispersion strengthened ferritic steel (ODS), and uranium-plutonium mixed oxide fuel (MOX) containing 5% americium, as well as both neptunium and americium.

In the Republic of Kazakhstan, the fast breeder reactor BN-350, commissioned in November 1972, was finally shut down in April 1999. The General Plan for the BN-350 decommissioning was developed within the framework of a Kazakh – US project. Currently, BN-350 is brought to "safe-store condition". Specifically, the following tasks were completed: unloading of all the fuel subassemblies, packaging of the spent fuel subassemblies into sealed cans which provide an additional safety barrier, removal of the caesium from the primary sodium and drainage of this sodium into storage tanks, and the partial drainage of secondary sodium into storage tanks. Ongoing are rad-waste processing and the preparation of the buildings and structures according to "safe-store condition" requirements. The project EAGLE was initiated in 2000 under a contract between the National Nuclear Centre of Kazakhstan RK and JNC (now JAEA). The project comprises the preparation and conduct of out-of-pile and in-pile experiments designed to address the key safety issues relevant to eliminating or mitigating the re-criticality potential during a postulated core-disruptive accident in future commercial sodium cooled FRs.

In the Republic of Korea, the Ministry of Science and Technology established the "Comprehensive Nuclear Energy Promotion Plan" in 2001, outlining the basic framework of the country's nuclear energy R&D programme. This Plan is based on the following requirements for future nuclear power plants: effective resource utilization, waste minimization and reduced environmental impacts, economic competitiveness, enhancement of safety and reliability, proliferation resistance and physical protection. The Plan suggests the development of liquid metal reactor technologies for an efficient utilization of the uranium resources with an emphasis on the development of basic key technologies. The work scopes of the project under this Plan include reactor design studies, development of computational tools, and the development of sodium technologies. In the Nuclear Technology Roadmap established in 2005, the sodium cooled FR was chosen as one of the most promising future reactor concepts that is deployable by 2030. Sodium cooled FR development efforts in the Republic of Korea date back to 1992, when the Korea Atomic Energy Commission approved a long term R&D plan on a sodium cooled FR. Under this national long term programme, the Korea Atomic Energy Research Institute (KAERI) has been developing KALIMER (Korea Advanced Liquid Metal Reactor), a pool-type liquid metal cooled reactor. KAERI completed the conceptual design of the 150 MW(e) KALIMER in March 2002. The three-year 3rd phase of the programme started in April 2002 with the goal of developing key technologies and advanced FR design concepts. In 2004, the last year of the 3rd phase, the preliminary conceptual design of the 600 MW(e) KALIMER-600 was developed. Currently, KALIMER-600 work is directed towards the development of the basic key technologies, further substantiation of various advanced design concepts, and the development of analytical methods. With a strong emphasis on proliferation resistance, two core design concepts, which have a single enrichment fuel zone and no blankets, are now being developed for sustainable energy supply and radioactive waste transmutation. In addition, research and development work in the areas of passive residual heat removal, shortened intermediate heat transfer system piping, seismic isolation, and supercritical CO_2 Brayton cycle energy conversion systems are ongoing. The year 2006 is the last year of the KALIMER-600 conceptual design development project. It is envisioned that the country's sodium cooled FR technology development programme will enter a new phase from 2007 on with participation in the Generation IV sodium cooled FR collaboration. According to the current draft of the national mid and long term nuclear R&D programme, the objective of the sodium cooled fast reactor R&D programme is to develop the conceptual design of a sodium cooled FR consistent with the Generation IV "Sodium Cooled Fast Reactor System Research Plan".

In the Russian Federation, with 147.6 TWh produced in 2005, the share of nuclear electricity production is about 16%. The strategy and the rate of development of nuclear power are currently re-examined in the Russian Federation. There are indications that the new goal for the development of nuclear energy in the Russian Federation is to increase its share up to 25% by 2025. Achieving this goal would require commissioning of about two power units per year. Based on its successful experience with FRs such as the BR-10, BOR-60 and BN-600 (8 April 2006 marked the 26th anniversary of the first power production with BN-600, currently the largest operating FR in the world, that has produced cumulatively over 96.2 TWh of electricity), work continues on the already licensed BN-800 [800 MW(e)]. The construction of this reactor is under way, and its commissioning is planned for 2012. By now, 22 auxiliary systems have been delivered and put into operation. Along with on-site construction work, manufacture orders of the components are placed with the various industrial partners. It is planned to begin main equipment manufacturing in 2006, in particular of the main and guard reactor vessels, as well as of primary circuit sodium tanks. The BR-10 research FR in Obninsk is in the stage of preparation for decommissioning. The BOR-60 experimental FR, in operation since 1969 Dimitrovgrad, is used for fuel, absorber, and structural material tests, isotopes production, tests of FR equipment, and also for heat and electricity production. BOR-60 has an operation license until 31 December 2009, after which its replacement with the new reactor BOR-60M is planned. As for R&D, the following activities were carried out during the year 2005:

(i) justification of lifetime extension for BN-600 and BOR-60; (ii) detailed design of BN-800; (iii) design of a pilot BN-800 uranium-plutonium mixed oxide fuel manufacturing plant; (iv) development of various concepts of advanced sodium cooled FRs, i.e. the large size sodium cooled commercial fast reactor BN-C, and the small size two-circuit nuclear power plant with sodium cooled fast reactor and gas turbine BN-GT; (v) development of heavy liquid metal cooled FR concepts, specifically, justification of the design of the lead cooled BREST-OD-300 reactor concept, as well as the development of the basic design of the lead-bismuth eutectic cooled SVBR-75/100 reactor concept; and (vi) basic R&D on gas cooled FR concepts.

The UK continues to support the international development of FR technology, mainly through participation in European and international collaborations. All of this work has until now been funded by BNFL, although it is intended that future funding will be provided by the Government. The work is conducted by Nexia Solutions, AMEC NNC, and Serco Assurance, with support from various universities, including Manchester and Imperial College. The Nuclear Decommissioning Authority (NDA), a non-departmental public body, set up in April 2005 under the Energy Act 2004 to take strategic responsibility for the UK's nuclear legacy) and UKAEA have also contributed to preservation of the UK's fast reactor knowledge base. The principal programmes of work related to FR systems are performed within the following frameworks: Generation IV, the EC's (EURATOM) framework programmes, and IAEA's TWG-FR. With regard to Generation IV, the UK has developed a domestic programme of work to underpin the development of three of the six Generation IV systems, specifically, the very high temperature reactor (VHTR), the sodium-cooled fast reactor (SFR), and the gas cooled fast reactor (GFR). It is expected that much of this domestic R&D programme will be offered as a contribution to the international Generation IV effort. Within the international Generation IV activities, R&D plans for each of these systems have been produced and plans for conducting the R&D collaborations are under discussion. Task sheets have been prepared and submitted to the coordinators for each system, detailing the proposed R&D contributions in each area (design and safety, fuel, materials, fuel cycle, balance of plant, etc.). As for EC's (EURATOM) framework programmes, the UK organizations participate in several EURATOM 6th Framework Programme which are concerned with FRs and their associated fuel cycle technologies, like the GCFR STREP – a gas cooled FR study. The UK strongly supports the activities of IAEA's TWG-FR, and participates in topical Technical Meetings wherever possible, e.g. planning for the IAEA CRP on "Analysis of, and lessons learned from operational experience with fast reactor equipment and systems", and participation in IAEA's coordinated research project (CRP) on "Updated codes and methods to reduce the calculational uncertainties of LMFR reactivity effects".

In the USA, the most important recent developments are centred on the new Global Nuclear Energy Partnership (GNEP) initiative, and on the progress of Generation IV activities. A key roadblock to development of additional nuclear power capacity is the concern over management of the nuclear waste produced by the plants, which requires disposal. Commercial spent nuclear fuel is the major contributor to high level radioactive waste generated in the country. With projected growth of nuclear energy, some estimates suggest that by 2100 the USA will have accumulated more than 300 000 t of spent fuel. However, the proposed Yucca Mountain Repository, by statute, can receive only 70 000 t of waste. Taking into account worldwide projections of nuclear power growth, it is surmised that eventually a new repository of a similar size will have to be built somewhere in the world every three to four years. It is envisioned that the utilization of the sodium cooled FR in a closed fuel cycle, as proposed within the GNEP framework, will result in better utilization of the geologic repository, namely, minimizing the need for additional repositories. Within the GNEP context, and aiming at clarifying the role of the FR in the closed fuel cycle, ANL is working with other U.S. national laboratories and USDOE in developing the initial R&D plan for the Advanced Burner Test Reactor (ABTR). The primary mission of the ABTR is to demonstrate actinide transmutation in a fast spectrum. In addition, the ABTR needs to demonstrate innovative technologies and design features that could be applied to follow-on commercial demonstration plants. The plant size should be small enough to result in an affordable plant cost, but large enough to enable the demonstration of key design features. The following innovative technologies and design features are being evaluated for inclusion into the ABTR: metal fuel, inherent passive safety, pyroprocessing, single rotating fuel transfer plug, seismic isolation system, electromagnetic primary pump technology, and a supercritical CO_2 Brayton cycle. As for Generation IV, the U.S. activities are focused on gas cooled fast reactors (GFR), lead cooled fast reactors (LFR), and small modular sodium cooled fast reactors (SMFR), which was accepted as a distinct third track in the most recent Generation IV sodium fast reactor (SFR) system research plan. The GFR activities are addressing the reference design features, safety systems capable of decay heat removal, fuel development, high temperature in-core materials, and the reference fuel cycle. The LFR R&D activities are focussing on 20 MW(e) [45 MW(th)] small secure transportable autonomous reactor (STAR) concepts (fuelled with nitride fuel, natural circulation heat transport, and long core life, e.g. 30 years). Except for the coolant being sodium, the design characteristics of the SMFR concepts are very similar to the LFR (i.e. long life, small size, proliferation resistant, inherently safe, deployable at remote locations, etc.).

All IAEA activities related to liquid metal cooled reactors are conducted within the framework of the Technical Working Group on Fast Reactors (TWG-FR), formerly International Working Group on Fast Reactors (IWG-FR), which is the only global forum for the review and discussion of LMFR programmes. This is of particular importance for those countries that are implementing FR programmes. In several cases, these programmes also include development, design and operation of experimental FRs. Participation in TWG-FR activities ensures that international safety practices are taken into account during the design and operation of FRs, and that no country with a FR programme is isolated in fast reactor technology development.

The TWG-FR has mostly focused on experimental and theoretical aspects of FR technology and safety. A benchmark test with experimental data was conducted to verify and improve the codes used for the seismic analysis of reactor cores. A CRP was conducted to apply acoustic signal processing for the detection of boiling or sodium/water reactions in LMFRs. Benchmark analyses addressed accident behaviour and design improvements of the Russian BN-800 reactor within the frame of a collaborative project between the IAEA and the European Community. In cooperation with the Department of Nuclear Safety, assistance was provided to ensure safe operation during the remaining lifetime and the development of an effective decommissioning programme for the BN-350 reactor in Kazakhstan. A CRP is being conducted with the objective to reduce the calculation uncertainties of the LMFR reactivity effects. The proposed benchmark models are based on a BN-600 mixed uranium-plutonium oxide fuelled hybrid core, and comparisons between analytical results and some experimental data obtained in the BFS zero-power facility are being performed. In addition to the hybrid core, a BN-600 core fully-fuelled with 60 GWd/t LWR plutonium and minor actinides was also considered. A new CRP on “Analysis of and lessons learned from operational experience with fast reactor equipment and systems” will be initiated later in 2006.

To foster the exchange of technical information and to contribute to the preservation of the base of LMFR technology knowledge, an updated LMFR database (FRDB), available on the Internet, has been developed. The FRDB contains detailed data of 36 experimental, prototype and commercial LMFRs. Each reactor plant is characterized by about 400 parameters, by design data and by relevant graphic materials.

Members of the TWG-FR
(formerly IWG-FR), established in 1967

Belarus	Kazakhstan
Brazil	Republic of Korea
China	Russian Federation
France	Switzerland
Germany	United Kingdom
India	USA
Italy	European Commission
Japan	OECD/NEA

In response to needs expressed by the Member States, and within a broader IAEA wide effort in nuclear knowledge management and preservation, and transmission to the younger generation, IAEA is implementing a concrete initiative on fast reactor data retrieval and knowledge preservation. This initiative provides an overall framework for the various programmes being implemented in the Member States. The main goals of the initiative are to halt the ongoing destruction of information, data retrieval, data assessment to determine which data and information should be retained, consideration of how information from different programmes could be linked, and what standards should exist and be employed in software and hardware to allow knowledge preservation over the next 30 to 40 years. In line with the objective of the initiative to develop a knowledge base into which existing knowledge preservation systems will fit, and which will complement and integrate ongoing and future efforts by Member States to preserve fast reactor data and knowledge, its implementation rests on both IAEA contributions, and Member States contributions. The IAEA contributes its own data and knowledge accumulated over nearly 40 years of activities performed within the frame of the TWG-FR. It is further creating a FR Knowledge Preservation Initiative network among interested Member States, and supporting and coordinating fast reactor data retrieval and knowledge preservation activities in Member States. Last, but not least, after having defined the structure of the knowledge preservation system, it is developing the means for precise and efficient knowledge retrieval through specialized taxonomies and classification systems, as well as the appropriate software tools. The fast reactor data and knowledge will be made accessible on suitable platforms, including an Internet based Knowledge Portal, implemented through a joint effort between some sections of the IAEA. The Member States joining the initiative, on the other hand, bear the responsibility for data retrieval and interpretation, as well as quality assurance.

Website for IAEA activities related to FRs:
http://www.iaea.org/inis/aws/fnss/index.html

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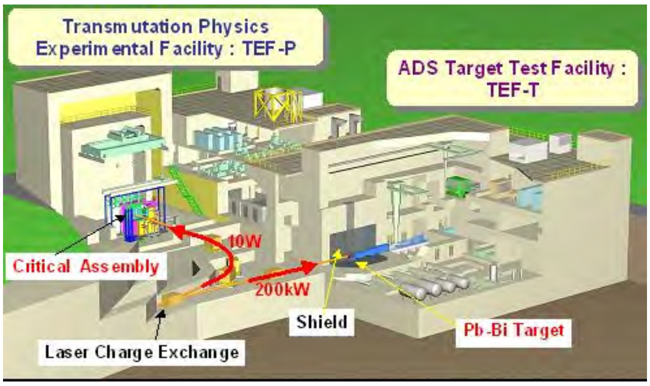
PARTITIONING AND TRANSMUTATION

High-level waste disposal is an element of paramount importance in the discussion of nuclear power generation sustainability. This, and the desire to reduce the quantity of long-lived waste material, have stimulated new interest in the transmutation of actinides and some long-lived fission products, and in emerging system technologies for energy production with reduced actinide generation.

One such system is the combination of a particle accelerator with a sub-critical nuclear reactor; another possibility is to reduce the generation of actinides by the introduction of the thorium fuel cycle. The assumed advantages of accelerator driven systems (ADS) - apart from their intrinsic low production of long-lived radioactive waste, and transmutation capability - are also enhanced safety characteristics and better long term resources utilization (e.g. in connection with thorium fuels). Important R&D programmes are being undertaken by various institutions in many Member States to substantiate these claims and advance the basic knowledge in this innovative area of nuclear energy development. In Asia, ADS R&D studies are pursued with both goals in mind: energy production with reduced radioactive waste production and decreased proliferation hazard, on the one hand, and long-lived waste transmutation, on the other. The R&D efforts are concentrated in China, India, Japan and the Republic of Korea. The programmes are presently conducted at national level, with some bilateral or multilateral cooperation agreements. In China, an ADS conceptual study lasted for about five years and was completed in 1999. In the next stage, a five-year programme of basic ADS physics research and related technology development was launched in 2000 within the framework of the China Ministry of Science and Technology (MOST) sponsored "major state basic research programme (973)" in the energy domain. This programme passed national review at the end of 2005. The R&D activities are focused on high-power proton accelerator (HPPA) physics and technology, reactor physics of external source driven sub-critical cores, nuclear data, and material studies. For HPPA, a 3.5 MeV high current injector consisting of an Electron Cyclotron Resonance (ECR) ion source, low energy beams transport (LEBT) and a radio-frequency quadrupole (RFQ) accelerating structure has been constructed. In the area of reactor physics studies, a series of neutron multiplication experimental studies are being carried out at the VENUS facility. VENUS is a zero power sub-critical neutron multiplying assembly driven by external neutrons produced by a pulsed neutron generator. Theoretical, experimental, and simulation studies on nuclear data, material properties, and nuclear fuel mass flows related to ADS are pursued aiming at providing the data needed for ADS system analysis studies. Involved in this research are CIAE (China Institute of Atomic Energy), IHEP (Institute of High Energy Physics), PKU-IHIP (Institute of Heavy Ion Physics in Peking University), and other institutions in academia.

In Japan, JAEA has continued ADS research and technology development for the transmutation of long-lived radioactive nuclides. The ADS proposed by JAEA is a lead-bismuth eutectic cooled fast sub-critical core rated at 800 MW(th). Various R&D activities were conducted during 2005 to investigate the feasibility of the ADS from the viewpoints of the accelerator, lead-bismuth eutectic as spallation target and core coolant, as well as the sub-critical core design. Moreover, conceptual design studies of the Transmutation Experimental Facility (TEF) were initiated. In the field of lead-bismuth eutectic studies, JAEA is performing in parallel static and loop corrosion tests. To study the spallation target window cooling performance of lead-bismuth eutectic, JAEA has constructed a thermal hydraulics loop. JAEA plans to build TEF at the Tokai site.



Transmutation Experimental Facility (TEF) planned at the Tokai site (*Credit: JAEA*)

The objective of this experimental facility is to study, within the framework of the J-PARC Project, the basic characteristics of ADS and transmutation technology from the viewpoint of reactor physics and spallation target technology and engineering. TEF consists of two buildings: the Transmutation Physics Experimental Facility (TEF-P) and the ADS Target Test Facility (TEF-T), as shown in the figure above. TEF-P is a zero-power critical facility where a low power proton beam is available to perform transmutation systems reactor physics studies, and to investigate the controllability of the ADS. As for TEF-T, this is a material irradiation facility that can accept a maximum 200 kW - 600 MeV proton beam onto the lead-bismuth eutectic spallation target. Although the TEF programme has not been approved yet officially, the J-PARC Project Team is now calling for the Preliminary Letters Of Intent (Pre-LOI) for experiments at the TEF. The objective of the Pre-LOI is to identify interested groups and potential contributions, to ensure that these proposals are reflected in the definition of the specifications and the layout of the TEF, and to establish an appropriate collaboration framework between J-PARC and the anticipated external users in the field of nuclear science and engineering.

In the Republic of Korea, KAERI has been working on ADS since 1997. The KAERI ADS system is called HYPER (HYbrid Power Extraction Reactor). HYPER research and development started as a 10-year nuclear research programme funded by the Government. KAERI's ADS research activities consist of 3 stages. A basic concept of HYPER was established in the first stage (1997-2000). In the second stage (2001-2003), the basic technology related to HYPER was investigated, and work on the conceptual design started. HYPER's conceptual core design was almost finished in the second stage. The third R&D stage (2004-2006) started in March 2004. Improvements to the core design and core transient studies were performed in the first year of the third stage. Target transient studies are planned for the second year of the third stage. The conceptual design of the HYPER core will be completed in the third stage. The investigation of key technologies will also be continued in the third stage. Regarding experimental research, fuel and lead-bismuth eutectic studies were performed during the second stage. Uranium surrogate fuel was fabricated and tested. KAERI joined the MEGAPIE project in 2001 for lead-bismuth eutectic research. KAERI also installed a static lead-bismuth eutectic corrosion test device in 2003 and started experimental work. In 2004, KAERI started the construction of a lead-bismuth eutectic corrosion loop. The isothermal part of the loop was completed in 2005, and testing is ongoing. Operation will start in June 2006. The non-isothermal part of the loop will be completed in 2006.

In Europe, the main driving force behind ADS is long-lived waste transmutation, but the ADS capability to produce energy is also investigated. The national (Belgium, France, Germany, Italy, Spain, Sweden) programmes on ADS R&D are converging towards the demonstration of the basic aspects of the ADS concept. These R&D activities are conducted both nationally and as joint efforts within the sixth and upcoming seventh framework programme of the European Union (EU), particularly the integrated projects IP-EUROTRANS and IP-EUROPART. The former is a large integrated project aimed at developing a preliminary design and supporting technologies for a European ADS demonstrator. The latter is a large integrated project which aims at developing the fuel cycle technologies which complement the EUROTRANS system technologies.

The Russian Federation also devotes R&D efforts to the development of the ADS technology. These studies are strongly coupled with advanced fuel cycle studies that aim at waste minimization and at a strong overall simplification of the nuclear fuel cycle (e.g. molten salt). Recent ADS R&D highlights in the Russian Federation include: (i) the comparative analysis of various approaches to the issues of incineration of long-lived radioactive waste using ADS and choice of the most effective option for further development; (ii) the development and construction of the sub-critical assembly SAD at JINR in Dubna within the framework of an ISTC project; (iii) the construction activities related to an experimental ADS based on a decommissioned heavy water reactor and the pulsed 36 MeV proton linear accelerator ISTRA-36 at ITEP in Moscow; (iv) the experimental studies of neutron cross sections of various isotopes in the high energy range up to 150 MeV at various institutions around the country; (v) the development of an ADS based on electron accelerators at IPPE in Obninsk; and (vi) the development and substantiation of critical and sub-critical molten salt reactor concepts with closed nuclear fuel cycle at RSC KI in Moscow.

IAEA activities in the ADS area, which are also carried out in the frame of the TWG-FR, include preparation of status reports on advanced technology development, conduct of technical information exchange meetings and coordinated research projects (CRPs) on the use of thorium fuel in accelerator driven systems and reactors to constrain plutonium production and to reduce long-term waste toxicities. In particular, the IAEA provided for a review and comparison of different options to achieve these aims, including review of new technical measures to achieve proliferation resistance. In another TWG-FR activity, participants from 20 institutions in 15 Member States and one international organization joined forces in the CRP on "Studies of advanced reactor technology options for effective incineration of radioactive waste". The final goal of this CRP is to deepen the understanding of the dynamics of transmutation systems, e.g. the ADS, especially of systems with deteriorated safety parameters, to qualify the available methods, specify the range of validity of these methods, and formulate requirements for future theoretical developments. IAEA is also implementing a CRP on "Analytical and experimental benchmark analyses of accelerator driven systems". The overall objective of this CRP is to increase the capability of interested Member States in developing and applying advanced reactor technologies in the area of long-lived radioactive waste utilization and transmutation. Its specific objective is to improve the present understanding of the coupling of an external neutron source [e.g. a spallation source in the case of the accelerator driven system (ADS)] with a multiplicative sub-critical core. Participants from 27 institutions in 18 Member States are performing computational and experimental benchmark analyses using integrated calculation schemes and simulation methods. To reach the objectives of the CRP, experimental benchmarking is of paramount importance. Hence, the CRP aims at integrating some of the planned experimental demonstration projects of the coupling at power between a sub-critical core and an external neutron source (e.g. YALINA Booster in Minsk, Belarus, and SAD at JINR, Dubna, Russian Federation). It is important to underline the common objective of these experimental facilities, which is to validate computational methods, obtain high energy nuclear data, characterize the performance of sub-critical assemblies driven by external sources, and, last but not least, to develop and improve techniques for sub-criticality monitoring.

To harmonize efforts, the elaboration of a database of existing and planned experimental facilities, as well as R&D programmes for accelerator driven systems and related research and development was initiated in 1997. Presently, the WWW-based version of the database is operational and open to all users. At the same time, Member States have been solicited to intensify data collection efforts.

Website for IAEA activities related to P&T:
http://www.iaea.org/inis/aws/fnss/index.html,

IAEA contact for P&T: A.Stanculescu@iaea.org

NUCLEAR DESALINATION

Experience with nuclear desalination

Number of reactors	13
Number of countries with experience	4
Experience in reactor-years	247

For human life, a sufficient amount of water and its adequate quality are essential. The scarcity of freshwater and especially potable water is jeopardizing many regions of the world. By 2025, about two thirds of the world population may suffer from high or moderate water shortages, particularly in the African region, Latin America and South East Asia. Seawater desalination offers one of the most promising alternatives for the supply of potable water. The worldwide cumulative seawater desalination capacity has steadily increased over the past few decades, and this trend is expected to continue into the foreseeable future. In order to contribute to the solution of this problem, the IAEA conducts a programme on nuclear seawater desalination, i.e. the production of potable water using nuclear energy.

An objective of the IAEA's nuclear power technology development programme is to increase the exchange of information on the introduction of nuclear desalination[4] and other non-electrical applications of nuclear energy, with the main focus being placed on nuclear desalination.

Since the Member States expressed a renewed interest in utilizing nuclear energy for seawater desalination at the IAEA General Conference in 1989, the IAEA has reassessed the technical and economic potential of nuclear energy for seawater desalination in the light of experience gained during the past decades. This assessment was carried out in cooperation with many institutions and experts from Member States. The results have been reported to the General Conference and the strengthening of the activity has been recommended continuously.

In order to provide the IAEA with advice and guidance for fulfilling General Conference resolutions on activities in nuclear seawater desalination, the International Nuclear Desalination Advisory Group (INDAG) was established in 1997.

Experience in nuclear desalination has been gained in Kazakhstan and Japan. The fast breeder reactor BN-350 in Kazakhstan had for many years been used partly for desalination until 1999. Several nuclear power units in Japan are equipped with seawater desalination facilities to get fresh water for make-up of the plant water system and in-plant household use. The experience has proven technical feasibility of nuclear seawater desalination over the 175 reactor-years of successful operation. Relevant technical experience has also been accumulated in the Russian Federation, Eastern European countries and Canada in utilizing nuclear heat for district heating and other process heat use. Successful operating experience in such applications exceeds 1000 reactor-years.

INDAG Members, Term III (2005-2008)

Argentina	Libyan Arab Jamahiriya
China	Morocco
Egypt	Pakistan
France	Russian Federation
India	Saudi Arabia
Israel	Tunisia
Japan	USA
Republic of Korea	

Through IAEA programmes, more than twenty Member States have been involved in the assessment of the potential for nuclear desalination.

The "Options Identification Programme for Demonstration of Nuclear Desalination" gave momentum to several Member States to consider evaluating, planning, or in some cases, initiating nuclear desalination projects under country-specific conditions. The IAEA is providing a framework for international cooperation in these demonstration projects in order to share experience and knowledge between Member States interested in deploying nuclear desalination. Small and medium sized reactors are of particular interest for non-electrical application in developing countries.

China has initiated a pre-feasibility study of a nuclear seawater desalination plant in Yantai area using an NHR-200 coupled with the vertical tube multi effect distillation (MED) process. The production capacity of the plant will be 160 000 m^3/d.

Egypt has completed its feasibility study of a nuclear cogeneration plant (electricity and water) at the El-Dabaa site under the IAEA technical cooperation project. Egypt has also completed the construction of a RO pre-heat experimental facility at El Dabaa.

France is coordinating the preparation of a follow-up project to EURODESAL, for an ambitious proposal under the International Cooperation with Mediterranean Countries (INCO/MED) programme of the 6th Framework Programme of the European Commission

India is setting up a 6300 m^3/d hybrid multi stage flash (MSFRO) nuclear desalination demonstration plant at the PHWR station at Kalpakkam. The RO segment was commissioned in 2002 and the full plant is due to be completed in 2007.

[4] ***Nuclear desalination*** is defined to be the production of potable water from seawater in a facility in which a nuclear reactor is used as the source of energy (electrical and/or thermal) for the desalination process. The facility may be dedicated solely to the production of potable water, or may be used for the generation of electricity and the production of potable water, in which case only a portion of the total energy output of the reactor is used for water production. In either case, the notion of nuclear desalination is taken to mean an integrated facility in which both the reactor and the desalination system are located on a common site and energy is produced on-site for use in the desalination system. It also involves at least some degree of common or shared facilities, services, staff, operating strategies, outage planning, and possibly control facilities and seawater intake and outfall structures

Nuclear desalination demonstration plant at the PHWR station at Kalpakkam

Indonesia has completed a study on "Preliminary economic feasibility of nuclear desalination in Madura Island" under the technical assistance of the IAEA's Interregional Technical Cooperation Project.

In the Republic of Korea, the conceptual and basic design of SMART with a desalination system was successfully completed. A construction project of the SMART plant with one-fifth scaled power with a desalination unit was launched. The plant is scheduled for operation in 2008.

Pakistan is constructing a 4800 m^3/d MED thermal desalination plant coupled to a PHWR at KANUPP, Karachi. It is expected to be commissioned by the end of 2007.

In the Russian Federation the floating power unit project development is coming to an end, and construction of a pilot plant at the shipyard in Severodvinsk, Arkhangelsk Region, is planned for 2007–2008.

Tunisia has now completed a pre-feasibility study of a co-generating nuclear desalination plant for the La Skhira site in the south of Tunisia (TUNDESAL project) under the IAEA's interregional technical cooperation project.

To assess and compare different energy and technology options for desalination, IAEA has developed a computer software package for economic assessment of nuclear and fossil options in combination with various desalination processes. A CD-ROM copy of the Desalination Economic Evaluation Program (DEEP) is available, cost-free, to potentially interested users. As of January 2004, DEEP was distributed to some 250 users in over 40 Member States of which 100 license agreements have been established. A new version of DEEP (DEEP-3), including improved performance and cost models, as well as a user-friendlier interface, was released in September 2005. It is freely available for download under a license agreement.

Safety of nuclear desalination installations is addressed in cooperation with the Department of Nuclear Safety. The economic competitiveness of nuclear desalination was also assessed in a comprehensive economic study and results are available in IAEA-TECDOC-1186.

To further assist Member States in the planning and implementation of possible nuclear desalination programmes and projects, guidelines were prepared for the introduction of nuclear desalination, which are available in the IAEA publication: "Introduction of nuclear desalination: A guidebook" (Technical Reports Series No. 400, 2000).

The coordinated research project (CRP) on "Optimization of the coupling of nuclear reactors and desalination systems" which ended in December 2003 has provided details of optimum coupling configurations of nuclear and desalination systems, evaluated their performance and identified technical features, which may require further assessment for detailed specifications of large-scale nuclear desalination plants. The results of the CRP were published in IAEA-TECDOC-1444 in June 2005. A CRP on "Economic research on, and assessment of, selected nuclear desalination projects and case studies" was initiated in February 2002. The objective is to contribute to enhancing the prospects for the demonstration of nuclear desalination and its successful implementation in Member States. The CRP will evaluate the economic aspects and investigate the competitiveness of nuclear desalination under specific conditions in case studies; identify innovative techniques leading to further cost reduction; and refine economic assessment methods and tools.

The IAEA cooperated with two NGOs, the World Council of Nuclear Workers (WONUC) and the Moroccan Association of Nuclear Engineers (AIGAM), on an international conference on nuclear desalination held in Marrakesh, Morocco, 16-18 October 2002. The IAEA contributed to the event by sponsoring the attendance from developing countries, offering direct financial support to the organizers to help meet the cost of the conference and by organizing a day-long IAEA session on "Advances in Nuclear Desalination".

IAEA is organizing an International Conference on Non-electrical Applications of Nuclear Power: Seawater Desalination, Hydrogen Production and other Industrial Applications, in cooperation with NEA/OECD and the International Desalination Association and hosted by the Japan Atomic Energy Agency at O-arai, Japan in April 2007.

Website for IAEA activities related to nuclear desalination: http://www.iaea.org/nucleardesalination,

IAEA contact for nuclear desalination: M.Methnani@iaea.org

INTERNATIONAL PROJECT ON INNOVATIVE NUCLEAR REACTORS AND FUEL CYCLES (INPRO)

The IAEA General Conference (2000) invited "all interested Member States to combine their efforts under the aegis of the IAEA in considering the issues of the nuclear fuel cycle, in particular by examining innovative and proliferation-resistant nuclear technology" (GC(44)/RES/21) and also invited Member States to consider contributing to a task force on innovative nuclear reactors and fuel cycles (GC(44)/RES/22). In response to this invitation, the IAEA initiated, in 2000, the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). Thereafter, INPRO activities have been continuously endorsed by resolutions of the IAEA General Conferences and corresponding United Nations General Assemblies.

INPRO is addressing a full spectrum of user requirements for innovative technologies and has developed a methodology and guidance for the comparison of different innovative approaches to nuclear energy systems taking into account variations in potential demands across countries. INPRO can make major contributions to ensure a meaningful role of nuclear energy in worldwide sustainable development within the 21st century by focusing on economic aspects, infrastructure (legal and institutional, economic and industrial, socio-political and human resources) and environmental issues, as well as on those areas where the IAEA can make unique contributions, such as proliferation resistance, nuclear safety and security, waste management, and by providing assistance to Member States in the definition of consistent nuclear strategies and in fostering increased international cooperation. INPRO is also examining legal and institutional needs to facilitate development and deployment of innovative nuclear energy systems (INSs) in certain groups of countries and worldwide.

The objectives of INPRO, as defined in the Terms of Reference, are:

- To help to ensure that nuclear energy is available to contribute in fulfilling, in a sustainable manner, energy needs in the 21st century;
- To bring together all interested Member States, both technology holders and technology users, to consider jointly the international and national actions required to achieve desired innovations in nuclear reactors and fuel cycles that use sound and economically competitive technology, based– to the extent possible – on systems with inherent safety features and minimize the risk of proliferation and the impact on the environment;

INPRO is an IAEA-wide project, being coordinated by the Department of Nuclear Energy with contributions from all relevant IAEA departments and divisions. The framework for implementation of the project consists of the following:

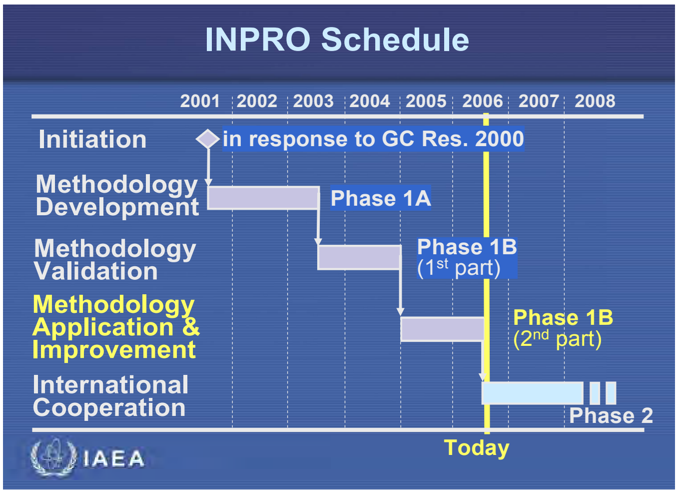
- The Steering Committee (SC), comprising as members, senior officials from INPRO Members and, as observers, representatives from interested IAEA Member States and International Organizations. IAEA project management is also represented. The Steering Committee meets as appropriate (approximately two times per year) to provide overall guidance, advise on planning and methods of work and to review the results achieved;
- The International Coordinating Group (ICG), comprising cost free experts from INPRO Members and a regular staff specially assigned for INPRO, which coordinates and implements the project on the basis of experts' work in Member States and International Organizations;
- Technical experts from IAEA Member States, which are convened as appropriate by the ICG to consider specific subjects; and
- The IAEA support, including project management, coordination, administrative and technical support.

As of August 2006, the following 27 Member States and International Organizations have become INPRO Members: Argentina, Armenia, Belarus, Brazil, Bulgaria, Canada, Chile, China, Czech Republic, France, Germany, India, Indonesia, Japan, Republic of Korea, Morocco, Pakistan, Russian Federation, Slovakia, South Africa, Spain, Switzerland, Netherlands, Turkey, Ukraine, USA, and the European Commission, and the membership is increasing. Members contribute to the project by providing funds, experts and studies.

In total, 29 cost free experts have been nominated by INPRO Members and worked or continue to work at the IAEA as members of the INPRO International Coordinating Group.

Prior to 2004 INPRO was implemented using mostly extrabudgetary resources offered by INPRO Members. The extrabudgetary contributions in 2003–2005 were provided by Bulgaria, Canada, Pakistan, Switzerland, Turkey, and the Russian Federation. In July 2003, the IAEA Board of Governors agreed to include INPRO partly in the regular budget of the IAEA, starting from 2004.

The project is implemented in two phases. Phase 1, started in 2001, includes two sub phases, Phase 1A and Phase 1B (parts 1 and 2).



INPRO schedule

The main output of Phase 1A (completed in June 2003) is IAEA-TECDOC-1362 "Guidance for the evaluation of innovative nuclear reactors and fuel cycles" issued in June 2003. The report provides a methodology for assessment of innovative nuclear energy systems as based on the defined set of basic principles, user requirements and criteria in the areas of economics, sustainability and environment, safety, waste management, proliferation resistance and recommendations on cross cutting issues.

The main output of Phase 1B (Part 1), completed in December 2004, is IAEA-TECDOC-1434 "Methodology for the assessment of innovative nuclear reactors and fuel cycles". The report incorporates the outputs of 14 case studies performed by experts from 7 INPRO Member States for the validation of the INPRO methodology through its trial application to the assessment of selected INSs, including the CAREM-X system with the CAREM integral type small pressurized water reactor and SIGMA fuel enrichment process (Argentina); Advanced Heavy Water Reactor (AHWR) and associated U-Pu-Th fuel cycle including FBR and ADS for transmutation of waste (India); DUPIC fuel cycle technology (Republic of Korea); BN sodium cooled reactor family and associated equilibrium fuel cycles (Russian Federation); pebble-bed high temperature reactor (China); molten salt reactor (Czech Republic); and other systems.

Based on a decision of the 9th INPRO steering committee, INPRO has entered into Phase 2 in July 2006. Terms of Reference for Phase 2 foresee that INPRO activity will continue in three main directions: (1) methodology oriented activities, (2) institutional/infrastructure oriented activities, (3) collaborative projects.

The framework and implementation options for R&D collaborative projects for INS development within Phase 2 were worked out by an ad-hoc meeting in April 2006. The framework, which includes creation of synergy with other international initiatives on nuclear innovation, was endorsed by the 9th Steering Committee held in July 2006.

Recently, at the G-8 meeting held on 16 July 2006, in St. Petersburg, Russian Federation, the heads of state and government adopted the following statement on global energy security: "The development of innovative nuclear power systems is considered an important element for efficient and safe nuclear energy development. In this respect, we acknowledge the efforts made in the complementary frameworks of the INPRO project and the Generation IV International Forum".

Major elements of the current activities under direction 1 include the finalization of the INPRO User Manual, which will assist users in the application of the methodology for INS assessment, as well as defining and modelling of INS deployment scenarios, and facilitation of INS assessments by INPRO Members on a national or international basis. Seven out of the expected nine chapters of the User Manual for methodology have been released by July 2006 and the other two are planned to be released by the end of 2006.

Several assessments of INS are being performed by INPRO Members on a national or international basis:

- Joint assessment based on a closed fuel cycle with fast reactors (Russian Federation, Canada, China, France, India, Japan , Republic of Korea, and Ukraine);
- Assessment of hydrogen generating INS in national energy mix (India);
- Assessment of the transition from the current fleet towards Generation IV fast neutron systems (France);
- Assessment of additional nuclear generation capacity in the country for the period 2010-2025 for the evaluation of NFC strategies (Argentina);
- Assessment of INS for countries with a small electricity grid (Armenia);
- Assessment of the complete DUPIC fuel cycle in the area of proliferation resistance (Republic of Korea);
- Two independent assessments of IRIS and FBNR (Brazil);
- Assessment of NPP economics (Morocco);
- Assessment of advanced HTGR (China);
- Assessment of national INS (Ukraine); and
- Assessment of INS to meet energy demand during periods of raw materials insufficiency (Czech Republic, Bulgaria, Poland, Russian Federation, Slovakia).

The assessments performed are expected to contribute to identifying needs and platforms for R&D collaborative projects on an international scale and also to provide valuable feedback for further improvement of INPRO methodology.

While some INPRO Members may require IAEA assistance in assessment of various INS options, the main objective of Phase 2 is to encourage and support IAEA Member States in facilitating the development, demonstration and deployment of safe, competitive, environmentally clean, and proliferation resistant INSs for sustainable development.

The strength of INPRO can be seen in the following main areas:

- Motivation: INPRO aims at integrating views from all stakeholders, notably from both nuclear technology developers and nuclear technology end users. User requirements developed with the participation of end users are an essential element in the first phase of INPRO.
- Time horizon: The time horizon for INPRO covers the next five decades. Energy scenarios for the period envisaged are determined by an expected transformation of the energy sector in light of limited fossil fuel supplies and potential climate change; new applications such as hydrogen as an energy carrier and seawater desalination for the production of potable water will be considered.
- Scope: INPRO looks at the whole range of innovative nuclear technologies for both reactors and fuel cycles including the environment, spent fuel and waste, but also institutional aspects and infrastructure. INPRO is aimed at examining the prospects of nuclear technology against this very broad background.
- IAEA Mandate: INPRO was initiated through a resolution of the IAEA General Conference and received its mandate from IAEA Member States. In turn, INPRO is established as an open process, and access to results is given to all IAEA Member States.

- Proliferation resistance: The unique mandate of the IAEA in the area of safeguards helps to ensure that the issue of proliferation resistance will be considered at every stage of INPRO.
- Synergy: INPRO avoids duplication of other IAEA activities and takes advantage of synergies with other international initiatives on nuclear energy technology development.

Website for INPRO: http://www.iaea.org//INPRO

IAEA contact for INPRO: A.Omoto@iaea.org

USER FRIENDLY EDUCATION WITH NUCLEAR POWER PLANT SIMULATORS

Computer-based tools are becoming standard components in education. In the field of nuclear engineering education, important strides have been taken in recent years to provide a range of education and training services based on the use of nuclear reactor simulators.

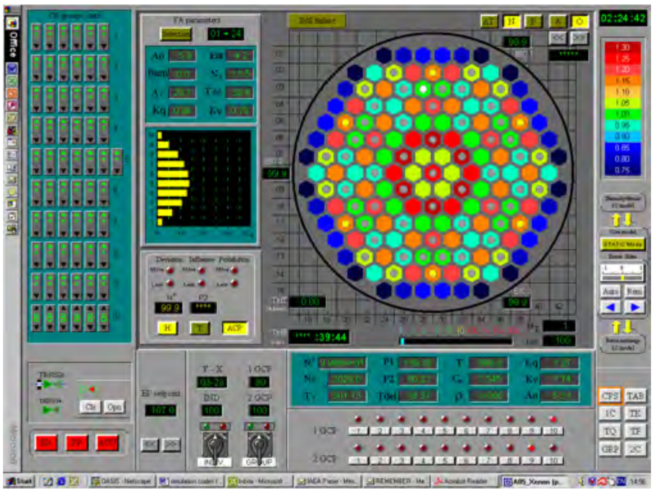
To assist Member States in nuclear education and training, the IAEA sponsors the development of nuclear power plant simulators which operate on personal computers and which simulate responses of a number of reactor types to operating and accident conditions. These simulators are not full-scope simulators for operator training, nor are they for detailed design or safety analyses. However, they do provide the general response characteristics of HWRs, PWRs and BWRs, and have very illustrative screens to provide the plant response information in a very interesting way helping to motivate students to learn about nuclear power plants.

Presently, the IAEA has the following NPP simulators for education: CANDU, Advanced CANDU, PWR with active safety systems; PWR with passive safety systems, WWER-1000 and a BWR.

The IAEA arranges for the development of NPP simulators for education, organizes training courses and workshops, and distributes the simulators and the associated users manuals.

Since 1997, fourteen workshops have been held, in Egypt, Saudi Arabia, the Republic of Korea, Italy, USA and at the IAEA Headquarters in Vienna, Austria. Training has been given, and reactor simulators have been distributed to more than 250 participants from close to 50 countries, for educational purposes. The workshops are currently an annual activity sponsored by the International Centre for Theoretical Physics, Trieste, Italy, and the IAEA.

The application of the simulation programs is essentially limited to providing general response characteristic of selected types of power reactor systems and they are not intended for plant-specific purposes such as design, safety evaluation, licensing or operator training.



WWER-1000 Simulator Screen

Website for NPP simulators:
http://www.iaea.org/OurWork/ST/NE/NENP/NPTDS/Projects/edu.html

IAEA contact for NPP simulators: J.Cleveland@iaea.org

SUPPORT TO TECHNICAL COOPERATION ACTIVITIES

To foster the global realization and sharing of the benefits of technology advances in nuclear energy, several specific technical cooperation projects related to the nuclear power technology development activities described above have been organized.

Current international technical cooperation (TC) projects cover several areas in nuclear desalination and design and technology development for advanced nuclear reactors.

A pre-project study was conducted to provide a basis for a decision on the installation of a desalination plant in Morocco based on a small heating reactor. Assistance was given to North African countries in the assessment and further development of national capabilities to support nuclear desalination programmes and to promote regional cooperative activities in this field. Also assistance is being provided to Egypt for its feasibility study on a nuclear desalination project at the El-Dabaa site. A series of expert missions on an economic evaluation methodology software package for nuclear desalination and on training for an educational nuclear reactor simulator personal computer software package have been conducted.

An interregional TC project on “Integrated nuclear power and desalination system design” was launched in 1999. The project was planned to encompass international collaboration between technology suppliers and prospective recipients (end users) for the joint development of desalination at a specific site or sites. At the kick-off meeting in 1999 participants from potential end users and/or technology providers exchanged information on possible collaboration in implementing nuclear desalination demonstration projects.

A protocol of the joint study on “Preliminary economic feasibility of nuclear desalination in Madura Island, Indonesia” has been prepared and signed between Indonesia and the Republic of Korea and studies were launched in 2002. The preliminary feasibility report and the URD are now ready for submission to the Government. Tunisia and France signed a protocol and launched a nuclear desalination pre-feasibility study for the La Skhira site in the south of Tunisia. The final report was submitted to the Tunisian Government in March 2005. Pakistan has completed the basic design study of a 4800 cubic meter per day desalination plant to be coupled to the KANUPP plant in Karachi. Construction of the plant is expected to be completed in 2006.

A TC project for Argentina “Evaluating the technological potential of advanced nuclear reactors” (ARG/04/086) was launched in the beginning of 2003. The objectives are to determine the requirements of the national energy market and the potential of advanced nuclear reactors as an option to meet future energy requirements in Argentina. The results will show the potential alternatives for technological developments for new NPPs for Argentina and the region, based on a significant reduction of capital layout for power plant construction, future demand of electricity, and sustainable technological capabilities in the region.

An interregional TC project INT/4/141, “Status and prospects of development for and applications of innovative reactor concepts for developing countries”, was launched in 2003 and proceeds with the participation of more than 30 developing countries from around the world. This project has the objective to provide a forum for information exchange between countries working on similar or different reactor lines and to receive input from countries, which may deploy these reactors. Although some of these developing countries are themselves actively working on new reactor concepts, others are keen to receive up to date advice on any innovative reactor concepts for electricity generation and process heat applications.

In the framework of this project a workshop was held in Beijing, China in 2004 on “Safety demonstration and market potential of high temperature gas cooled reactors”. At the end of the workshop, a safety test involving an anticipated transient without scram, was successfully demonstrated at the Tsinghua University HTR-10 test reactor.

For 2005, a workshop in Argentina on deployment and application potential of integral type PWRs for developing countries is being prepared, with the objective of bringing together technology holders and potential users of such reactors for information exchange and discussion of the state-of-the-art in design and technology development for integral type PWRs, and their deployment and application potential for developing countries. This workshop will also present experiences of developing countries (Argentina, Brazil, Mexico) in running a competitive nuclear industry.

Coordinated research projects related to nuclear power technology development

(September 2006)

International cooperative research programmes are established by the IAEA in areas that are of common interest to a number of Member States. These cooperative efforts are carried out through Coordinated Research Projects (CRPs), typically 3 to 6 years in duration, and often involving experimental activities. Such CRPs allow a sharing of efforts on an international basis, nurture team building and benefit from the experience and expertise of researchers from all participating institutes.

Natural circulation phenomena, modelling, and reliability of passive systems that utilize natural circulation

Argentina, Canada, China, France, Japan, Germany, India, Italy, Republic of Korea, Romania, Russian Federation, Slovakia, Spain, Switzerland, USA and the European Commission's Institute for Energy

The project is sharing experimental data on phenomena influencing natural circulation, applying methodology for investigating the reliability of passive systems, and preparing a state of the art report on natural circulation.

Evaluation of high temperature gas cooled reactor performance

China, France, Germany, Indonesia, Japan, Netherlands, Russian Federation, South Africa, Turkey, USA

This CRP involves the simulation of reactor physics and thermal hydraulic benchmark experiments being conducted by the HTTR and HTR-10 test reactors in Japan and China, as well as critical experiments on a mock-up of the PBMR core in the ASTRA critical facility in the Russian Federation. In addition, code-to-code benchmarking is also being conducted for reactor physics problems related to the PBMR and GT-MHR core designs, as well as the Pebble Bed Micro Model facility in South Africa. Participants are providing both pre- and post-test predictions of experimental results to contribute to the validation of computer codes for use in the design and safety analysis of modular HTGR reactors.

Updated codes and methods to reduce the calculational uncertainties of LMFR reactivity effects

China, France, Germany, India, Japan, Republic of Korea, Russian Federation, United Kingdom, USA

This CRP will establish the basis for quantifying and eventually decreasing the uncertainties in the calculation of the Doppler, the sodium density and other reactivity coefficients used in LMFR transient analyses.

Advances in high temperature gas cooled reactor fuel technology

China, France, Germany, Japan, Netherlands, Republic of Korea, Russian Federation, South Africa, USA

This CRP focuses on advances in coated fuel particle technology in areas such as fabrication, quality assurance and control, reactor performance, heating and PIE testing as well as performance modelling.

Studies of advanced reactor technology options for effective incineration of radioactive waste

Belgium, China, Czech Republic, France, Germany, Hungary, India, Japan, Republic of Korea, Netherlands, Poland, Russian Federation, USA, EC (JRC)

The CRP concentrates on the assessment of the transient behaviour of various transmutation systems. For a sound assessment of the transient and accident behaviour, the neutron kinetics and dynamics have to be qualified, especially as the margins for the safety relevant neutronics parameters are becoming small in a “dedicated” transmuter. The CRP will integrate benchmarking of transient/accident simulation codes focussing on the phenomena and effects relevant to various critical and sub-critical systems under severe neutron flux chances and rearrangements. The main thrust will be on long time-scale effects of transients initiated by strong perturbations of the core and/or the neutronic source. Changes of flux-shape and power caused by reactivity perturbations in systems with dedicated fuels and various Minor Actinide content will be one focus. For the transient analysis of such transmuters, besides neutronics, thermal-hydraulic and fuel issues are of importance.

The behaviour of different transmuter systems under various transient conditions will be assessed.

The CRP will investigate future needs both for theoretical means (data and codes) and experimental information related to the various transmutation systems.

The final goal is to deepen the understanding of the dynamics of transmutation systems, e.g., the accelerator driven systems, especially systems with deteriorated safety parameters, qualify the availability methods, specify the range of validity of methods, and formulate requirements for future theoretical developments. Should transient experiments be available, the CRP will pursue experimental benchmark work. Should transient experiments be available, the CRP will pursue experimental benchmark work. In any case, based on the results, the CRP will conclude on the potential need of transient experiments and make appropriate proposals for experimental programmes.

Economic research on, and assessment of, selected nuclear desalination projects and case studies

Argentina, Canada, China, Egypt, France, India, Republic of Korea, Pakistan, Russian Federation, Syrian Arab Republic, USA

This CRP is to contribute to the IAEA’s, efforts to enhance prospects for the demonstration and eventually for the successful implementation of nuclear desalination in Member States. This is to be achieved through research projects directed towards evaluation of economic aspects and investigation of the competitiveness of nuclear desalination under specific conditions in case studies, identification of innovative techniques leading to further cost reduction and refinement of economic assessment methods and tools.

Analytical and experimental benchmark analysed of accelerator driven systems (ADS)

Argentina, Belarus, Belgium, Brazil, China, France, Germany, Hungary, Italy, Japan, Netherlands, Pakistan, Poland, Russian Federation, Spain, Sweden, Ukraine, USA

The CRP will contribute to the generic R&D efforts in various fields common to innovative fast neutron system development, i.e. heavy liquid metal thermal hydraulics, dedicated transmutation fuels and associated core designs, theoretical nuclear reaction models, measurement and evaluation of nuclear data for transmutation, and development and validation of calculational methods and codes. Apart from analytical benchmark exercises, it will integrate some of the planned experimental demonstration projects of the coupling at power between a sub-critical core and an external neutron source (YALINA Booster in Minsk, Belarus, and SAD at JINR, Dubna, Russian Federation). Ultimately, the CRP’s overall objective is to make contributions towards the realization of a transmutation demonstration facility.

Analyses of and lessons learned from the operational experience with fast reactor equipment and systems

France, Japan, Republic of Korea, Russian Federation

The CRP will contribute to the preservation of the feedback ("lessons learned") from the commissioning, operation, and decommissioning of experimental and power sodium cooled fast reactors.

Small reactors without on-site refuelling

Brazil, Croatia, India, Indonesia, Italy, Japan, Lithuania, Morocco, Russian Federation, USA, Vietnam

The objective of this CRP is to increase the capabilities in Member States to achieve progress in the development and deployment of such reactors by formulating major requirements and increasing international cooperation for the development of key enabling technologies, including long-life cores, inherent and passive safety features and passive systems, and design and regulatory provisions to reduce or eliminate off-site emergency planning.

Potential of high temperature gas cooled reactors for process heat applications

China, France, Germany, Indonesia, Japan, Republic of Korea, Netherlands, Russian Federation, South Africa, USA

This CRP will serve as a platform for collaborative research on technical and economic aspects of coupling of High Temperature Gas Cooled Reactors (HTGR) to process heat applications such as hydrogen production and seawater desalination. The CRP will be coordinated with the existing available economic models from Nuclear Energy-Planning and Economic Studies Section and also will include consideration of the associated safety coupling aspects by involvement of Nuclear Safety Department in the Research Coordination Meetings. The CRP will produce a report updating the status of the available information and related R&D.

IAEA publications related to nuclear power technology development (1995-2006)

Series and No.	Title, Summary
2006	
IAEA-TECDOC-1499	**Intercomparison of techniques for inspection and diagnostics of heavy water reactor pressure tubes flaw detection and characterization** This publication reports on the first phase of the IAEA Coordinated Research Project (CRP) on Intercomparison of Techniques for HWR Pressure Tube Inspection and Diagnostics, dealing with flaw characterization by in-situ non-destructive examination (NDE) techniques. The participating laboratories prepared pressure tube (PT) samples containing artificial hidden flaws resembling real defects of concern. All samples were then inspected from the inside surface, as in real conditions. The originating laboratories subsequently analysed the sample inspection reports from investigating laboratories and compared the NDE flaw sizing estimates with their true values. Thus, the most successful NDE methods for detection, location and sizing of various types of flaws in PTs were identified. This publication details how the research was conducted and documents results from the flaw detection and characterization activities.
IAEA-TECDOC-1496	**Thermophysical properties database of materials for light water reactors and heavy water reactors** This database is intended to serve as a useful source of information on thermophysical properties data for water cooled reactor analyses. In particular, it aims at achieving improvements in safety and economics of future plants by helping to remove the need for large design margins to account for limitations of data and methods. The database has been developed into an internationally available Internet database (THERPRO) at Hanyang University (Republic of Korea), and now provides various materials properties data and an interactively accessible information resource and communications medium for researchers and engineers.
IAEA-TECDOC-1487	**Advanced nuclear plant design options to cope with external events** Developed through direct cooperation with the designers of 14 advanced NPPs, this TECDOC defines, collates, and presents the state-of-the-art in design features and approaches used to protect nuclear plants from external event impacts, making a focus on NPPs with evolutionary and, when possible, innovative designs. The TECDOC is designed to reflect best practices in member states and to provide technical and information background to assist designers of advanced NPPs in defining consistent strategies regarding selected design and site evaluation issues in relation to extreme external events. The issues addressed include, *inter alia*, siting, hazard definition and event combination criteria, reactor and plant design including inherent and passive safety features and active and passive systems, component qualification, and external event PSA.

Series and No.	Title, Summary
IAEA-TECDOC-1485	**Status of innovative small and medium sized reactor designs 2005: reactors with conventional refuelling schemes** The objective of this report is to provide Member States, including those just considering the initiation of nuclear power programmes, and those already having practical experience in nuclear power, with a balanced and objective information on important development trends and objectives of innovative SMRs for a variety of uses, on the achieved state-of-the-art in design and technology development for such reactors and on their design and regulatory status. The report is intended for many categories of stakeholders, including regulators, electricity producers, designers, non-electrical producers and policy makers. The main chapters of this report, addressed to all abovementioned groups of stakeholders, provide a summary of major specifications, applications and user-related special features of innovative SMRs. The annexes, intended mostly for designers and technical managers, provide detailed design descriptions of innovative SMRs focusing on their a potential to provide solutions in the areas of concern associated with future nuclear energy systems.
2005	
IAEA-TECDOC-1474	**Natural circulation in water cooled nuclear power plants phenomena, models and methodology for system reliability assessments** An important new approach incorporated into several advanced LWR and HWR designs involves the use of passive safety systems. This approach is expected to provide a very high level of safety and improved economics through design simplification. Considering the weak driving forces of passive systems based of natural circulation, careful design and analysis methods must be employed to ensure that the systems perform their intended function. This publication describes the present state of knowledge on natural circulation in water cooled nuclear power plants and passive system reliability. It presents extensive information on phenomena, models, predictive tools and experiments that currently support design and analysis of natural circulation systems, and highlights areas where additional research is needed.
IAEA-TECDOC-1451	**Innovative small and medium sized reactors; design features, safety approaches and R&D trends** This TECDOC summarizes the major features and application potential and identifies the technology and infrastructure development trends for about 30 designs of innovative small and medium sized reactors (SMRs) considered at an IAEA technical meeting held in June 2004.
IAEA-TECDOC-1444	**Optimization of the coupling of nuclear reactors and desalination systems** This document summarizes the results of the CRP on “Optimization of the coupling of nuclear reactors and desalination systems”. The overall scope of the CRP was to encompass research and development projects focused on optimized coupling of nuclear and desalination systems in the areas: nuclear reactor design intended for coupling with desalination systems; optimization of thermal coupling of NSSS and desalination systems; performance improvement of desalination systems for coupling; and advanced desalination technologies for nuclear desalination. Different coupling options between the various nuclear reactor types and desalination technologies have been investigated within the CRP and were optimized with respect to safety, operational flexibility, reliability/availability and economics.

Series and No.	Title, Summary
STI/PUB/1197	**The role of nuclear power and nuclear propulsion in the peaceful exploration of space** This publication provides details of a variety of radioisotope power systems, shows in what circumstances they surpass other power systems, and provides the history of the space missions in which they have been employed. The book also summarizes the use of on-board reactors and the testing done on reactor rocket thrusters as well as provides a review of current technology, a consideration of future applications, and a bibliography of further information on space nuclear technology. This publication also attempts to identify those R&D areas where space related nuclear power systems can be of practical relevance to efforts in innovative reactors and fuel cycle technology development that are currently being pursued within various international collaboration frameworks.
IAEA-TCS-21, 2nd edition	**WWER-1000 reactor simulator** This publication consists of course material for workshops on nuclear reactor simulation computer programs. The workshops are in two parts: techniques and tools for reactor simulator development; and the use of reactor simulators in education. Workshop material for the first part is covered in the IAEA Training Course Series No. 12, "Reactor Simulator Development" (2001). Course material for workshops using a pressurized water reactor (PWR) simulator developed for the IAEA by Cassiopeia Technologies Inc. of Canada is presented in the IAEA publication: Training Course Series No. 22 "Pressurized Water Reactor Simulator" (2003) and Training Course Series No. 23 "Boiling Water Reactor Simulator" (2003). This report deals with course material for workshops using a WWER-1000 reactor department simulator from the Moscow Engineering and Physics Institute.

2004

IAEA-TECDOC-1434	**Methodology for the assessment of innovative nuclear reactors and fuel cycles. Report of phase 1B (first part) of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)** This report documents changes to the basic principles, user requirements, criteria and the method of assessment that resulted from the second step of INPRO (referred to as Phase 1B (first part)), which started in June 2003 and ended in December 2004. During this step, Member States and individual experts performed 14 case studies with the objective of testing and validating the INPRO methodology. Based on the feedback from these case studies and numerous consultancies mostly held at the IAEA, the INPRO methodology has been significantly updated and revised, as documented in this report. The ongoing and future activities of INPRO will lead to further modifications to the INPRO methodology, based on the feedback received from Member States in light of their experience in applying the methodology. Thus, additional reports will be issued, as appropriate, to update the INPRO methodology.
IAEA-TECDOC-1406	**Primary coolant pipe rupture event in liquid metal cooled reactors** This TECDOC reviews the safety philosophy for the primary coolant (PCP) rupture event in pool type liquid metal fast reactors (LMFR), assesses the structural reliability of the PCP and the probability of rupture under different conditions (with/without in-service inspection), reviews the classification of the PCP rupture event in design basis/beyond design basis categories and discusses the applicable design safety limits, assesses the need for consequential analysis like pipe whip effects, primary pump seizure and multiple pipe rupture, and, last but not least, presents the results of analysis of the event per se for flows and/or temperatures and improved design concepts for minimizing the consequences to the core.

Series and No.	Title, Summary
IAEA-TECDOC-1405	**Operational and decommissioning experience with fast reactors** Given the present slow-down (at least in the West) in fast reactor technology development, and the concomitant retirement of many developers of this technology, data retrieval and knowledge preservation efforts in this area are particularly important. Operational experience constitutes an important aspect of any fast reactor knowledge base. It is within this context that the IAEA convened a topical technical meeting on feedback from operational and decommissioning experience with fast reactors, thus initiating a "lessons learned" process of (necessary step in the process of transforming "knowledge" into "wisdom"). The present publication presents the proceedings of this topical technical meeting that was held in March 2002 at CE Cadarache, France.
IAEA-TECDOC-1391	**Status of advanced light water reactor designs: 2004** The report is intended to be a source of reference information for interested organizations and individuals, among them decision makers of countries considering implementation of nuclear power programmes. Further, the report is addressed to government officials with an appropriate technical background and to research institutes of countries with existing nuclear programmes that wish to be informed on the global status in order to plan their nuclear power programmes including both research and development efforts and means for meeting future energy needs. The report is also intended to provide the public with unbiased information on nuclear power.
IAEA-TECDOC-1395	**Intercomparison and validation of computer codes for thermohydraulic safety analysis of heavy water reactors** Intercomparison and validation of computer codes used in different countries for thermal hydraulics safety analysis of heavy water reactors (HWRs) enhances the confidence in the predictions made by these codes. A set of reliable experimental data is necessary for conducting such intercomparison and validation exercises. Experimental results from a large-loss of coolant accident (LOCA) test simulating HWR LOCA behaviour that was conducted by Atomic Energy of Canada Ltd. (AECL) was selected for this validation project. This report provides a comparison of the results obtained from six participating countries, utilizing four different computer codes. General conclusions are reached and recommendations made.
2003	
IAEA-TECDOC-1382	**Evaluation of high temperature gas cooled reactor performance: Benchmark analysis related to initial testing of the HTTR and HTR-10** The TECDOC documents benchmark results on HTGR core physics and thermal-hydraulics, using data from the HTTR and HTR-10 test reactors. The work has been conducted in the framework of an IAEA coordinated research project (CRP) initiated in 1997, to assess design uncertainties and computational code performance.
IAEA-TECDOC-1365	**Review of national accelerator driven system programmes for partitioning and transmutation** With the objective of assessing the progress in the development of hybrid systems for P&T, as well as their potential role relative to future direction of the nuclear power worldwide development, the TECDOC presents a review of P&T related R&D programmes in Member States.
IAEA-TECDOC-1362	**Guidance for the evaluation of innovative nuclear reactors and fuel cycles. Report of phase 1A of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)** The TECDOC provides a Methodology for the Assessment of Innovative Nuclear Energy Systems as based on the defined set of Basic Principles, User Requirements, Criteria, and recommendations structured along the areas of Economics, Sustainability and Environment, Safety, Waste Management, Proliferation Resistance and Cross Cutting (infrastructure, institutional, legal, social, human resource) Issues.

Series and No.	Title, Summary
IAEA-TECDOC-1356	**Emerging nuclear energy and transmutation systems: core physics and engineering aspects** The TECDOC reviews the status of research and development activities in the area of hybrid systems for energy generation and transmutation, discusses specific scientific and technical issues covering the various R&D topics of these systems, and identifies activities in response to the open issues.
IAEA-TECDOC-1349	**Potential of thorium-based fuel cycles to constrain plutonium and reduce the long-lived waste toxicity** The TECDOC is the final report of an IAEA coordinated research project (CRP) initiated in 1995. This CRP examined different fuel cycle options in which plutonium can be recycled with thorium with the goal of plutonium incineration. The CRP also investigated the radio-toxicity accumulation in, and the transmutation potential of thorium-based cycles in current, advanced, and innovative nuclear power reactors.
IAEA-TECDOC-1348	**Power reactor and sub-critical blanket systems with lead and lead-bismuth as coolant and/or target material** The TECDOC presents a review of the R&D performed in the Member States in critical and sub-critical transmutation concepts, with emphasis on heavy liquid metal properties, and the experimental and analytical codes and data validation work.
IAEA-TCS-21	**WWER-1000 reactor simulator** This publication consists of course material for workshops on nuclear reactor simulation computer programs. The workshops are in two parts: techniques and tools for reactor simulator development; and the use of reactor simulators in education. Workshop material for the first part is covered in the IAEA Training Course Series No. 12, “Reactor Simulator Development” (2001). Course material for workshops using a pressurized water reactor (PWR) simulator developed for the IAEA by Cassiopeia Technologies Inc. of Canada is presented in the IAEA publication: Training Course Series No. 22 “Pressurized Water Reactor Simulator” (2003) and Training Course Series No. 23 “Boiling Water Reactor Simulator” (2003). This report deals with course material for workshops using a WWER-1000 reactor department simulator from the Moscow Engineering and Physics Institute.
IAEA-TCS-22	**Pressurized water reactor simulator workshop material** This publication consists of course material on the pressurized water reactor (PWR) simulator developed by Cassiopeia Technologies Inc. of Canada, prepared for use at workshops on nuclear reactor simulation computer programs, as described in more detail under TCS-21 above.
IAEA-TCS-23	**Boiling water reactor simulator** This publication consists of course material on the boiling water reactor (BWR) simulator developed by Cassiopeia Technologies Inc. of Canada, prepared for use at workshops on nuclear reactor simulation computer programs, as described in more detail under TCS-21 above.

2002

Series and No.	Title, Summary
IAEA-TECDOC-1326	**Design concepts of nuclear desalination plants** This publication presents material on the current status of nuclear desalination activities and preliminary design concepts of nuclear desalination plants, as made available to the IAEA by various Member States. It is aimed at planners, designers and potential end-users in those Member States interested in further assessment of nuclear desalination.

Series and No.	Title, Summary
IAEA-TECDOC-1319	**Thorium fuel utilization: options and trends (Proceeding of three IAEA meetings held in 1997, 1998 and 1999)** The use of thorium-based fuel cycles has been studied in the past, but on a much smaller scale as compared to uranium or uranium/plutonium cycles. Although based on boundary conditions and needs quite different from the present ones, those studies have permitted to identify many incentives for the use of thorium fuel. The TECDOC provides an assessment of the current status of this fuel cycle, its applications worldwide, its economic benefits, and its perceived advantages vis-à-vis other nuclear fuel cycles.
IAEA-TECDOC-1318	**Harmonization and validation of fast reactor termomechanical and thermohydraulic codes and relations using experimental data** The TECDOC is the final report of an IAEA Coordinated Research Project initiated in 1996 aiming at examining the ability of computer codes to predict the structural damage caused by thermal striping in areas of different temperature coolant mixing.
TRS-407	**HWRs – status and projected development** This report presents the status of HWR advanced technology in the areas of safety, fuel cycle flexibility and sustainable development, and economics, and the advanced technology developments needed in the following two decades to achieve the vision of the advanced HWR.
IAEA-TECDOC-1290	**Improving economics and safety of water cooled reactors: proven means and new approaches** With increasingly liberalized electricity markets around the world, and particularly the success of low-cost combined cycle gas turbines, incentives have increased for identifying means to achieve better NPP economics. The task on "Optimizing Technology, Safety and Economics of Water Cooled Reactors" was carried out during 1999-2002. The task included collaboration with eleven industrial organizations and four government agencies as well as the OECD-NEA and the European Commission. Its objective was to emphasize the need, and to identify approaches, for new nuclear plants with water cooled reactors to achieve competitiveness while maintaining high levels of safety. To achieve the largest possible cost reductions, proven means for reducing costs must be fully utilized, and new approaches (such as improved technologies, risk informed methods for evaluating the safety benefit of design features, and international consensus regarding safety requirements so that standardized designs can be built in several countries without major re-design efforts) should be developed and implemented. Proven means and new approaches are examined using the full breadth and capabilities of the IAEA, including expertise available at the IAEA.
IAEA-TECDOC-1289	**Comparative assessment of thermophysical and thermohydraulic characteristics of lead, lead-bismuth and sodium coolants** The TECDOC selects, reviews and documents the information on lead and lead-bismuth alloy coolants. It addresses thermalhydraulics issues, as well as physical and chemical properties. It attempts an assessment of these coolants and performs comparisons with the respective sodium characteristics.
IAEA-TECDOC-1288	**Verification of analysis methods for predicting the behaviour of seismically isolated nuclear structures** The TECDOC is the final report of an IAEA Coordinated Research Project initiated in 1996 aiming at the investigation of the base isolation for nuclear structures. The TECDOC summarizes the results of the computer codes and methodology validation and verification studies (comparisons with test data).

Series and No.	Title, Summary
IAEA-TECDOC-1281	**Natural circulation data and methods for advanced water cooled nuclear power plant designs** Proceedings of an TCM on Nuclear Circulation Data and Methods for Innovative Nuclear and Power Plants Design. The objective of this TCM were to assess the current base of experimental data and the applicability of current methodologies for computing natural convection phenomena in innovative reactor design, and to develop perspectives on needed improvements in models and supporting experimental data. This TECDOC provides the papers presented and summarized the discussions. The papers and discussions addressed both evolutionary and innovative designs for light and heavy water reactors.
IAEA-TECDOC-1264	**Reliability assurance programme guidebook for advanced light water reactors** This guidebook demonstrates how the designers and operators of future commercial nuclear plants can exploit the risk, reliability and availability engineering methods and techniques developed over the past two decades to augment existing design and operational nuclear plant decision-making capabilities.
C&S Papers Series 14/P	**Small and medium sized reactors: status and prospects** Proceedings of an International Seminar held in Cairo, Egypt on 27-31 May 2001 organized by the IAEA in cooperation with the OECD Nuclear Energy Agency and the World Nuclear Association.
AEN/NEA and IAEA 2002 Publication	**Innovative nuclear reactor development: opportunities for international cooperation** This report has been authored and produced by the "Three-Agency Study", a joint project of the International Energy Agency (IEA), the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA). The conclusions and recommendations contained in the report are the work of all three agencies.
Technical Reports Series No. 410	**Market potential for non-electrical application of nuclear energy** The report assesses the market potential of non-electric application of nuclear energy in the near (before 2020) and long (2020-2050) terms. The main non-electrical applications included are district heating, desalination (of sea, brackish and waste water) industrial heat supply, ship propulsion and energy supply for space rapt. A less detailed assessment of some innovative applications (e.g. hydrogen production and coal gasification) is also provided.

2001

Series and No.	Title, Summary
IAEA-TECDOC-1249	**Critical experiments and reactor physics calculations for low enriched HTGRs** Advanced gas cooled reactor designs currently under development are predicted to achieve a high degree of safety through reliance on innovative features and passive systems. The IAEA's activities in this field during the 1990's focused on three technical areas that are essential to providing this high degree of safety, but which must be proven. These technical areas are: (1) the neutron physics behaviour of the reactor core; (2) the ability of ceramic coated fuel particles to retain the fission products, even under extreme accident conditions; and (3) the ability of the designs to dissipate decay heat by natural transport mechanisms. To enhance confidence in predictions of neutron physics behaviour, the IAEA established a Coordinated Research Project (CRP) on Validation of Safety Related Physics Calculations for Low Enriched HTGRs. Countries participating in this CRP include China, France, Japan, Switzerland, Germany, Netherlands, USA and the Russian Federation. Its objective was to fill gaps in validation data for physics methods used for core design of gas-cooled reactors fuelled with low enriched uranium. Within this CRP, an international team of researchers was assembled at the PROTEUS critical experiment facility of the Paul Scherrer Institute, Villigen, Switzerland, to plan, conduct and analyze a new series of critical experiments focused on the needs of participating countries. In this CRP, experience from critical experiment programmes in the Russian Federation and Japan was also utilized.

Series and No.	Title, Summary
IAEA-TECDOC-1245	**Performance of operating and advanced LWR designs** Proceedings of a TCM hosted by E.ON Energie AG (Munich) in October 2000. The TCM provided a forum for information exchange on design features and technologies incorporated into LWR plants commissioned within about the last 15-20 years, and into evolutionary LWR designs still under development, for achieving performance improvements with due regard to stringent safety requirements and objectives. It also addressed on-going technology development expected to achieve further improvements and/or significant cost reductions.
IAEA-TECDOC-1239	**Critical experiments and reactor physics calculations for low-enriched HTGRs** This report documents the results of an IAEA Coordinated Research Project on Validation of safety related reactor physics calculations for low-enriched HTGRs. A mock-up of a pebble bed reactor core using fuel produced in Germany was constructed in the PROTEUS critical facility in Switzerland and reactivity experiments were conducted. The results and detailed configuration data are provided along with summary results of calculations of the experiments performed by the CRP participants.
IAEA-TECDOC-1238	**Gas turbine power conversion systems for modular HTGRs** The information presented in this report was developed from an IAEA Technical Committee Meeting on “Gas Turbine Power Conversion Systems for Modular HTGRs”, held from 14-16 November 2000 in Palo Alto, California. The TCM provided a forum for participants to discuss and share the status of their individual programmes associated with the design and analysis of systems and components for gas turbine modular HTGR power conversion systems.
IAEA-TECDOC-1236	**Design and evaluation of heat utilization systems for the high temperature engineering test reactor** This report documents the results of an IAEA Coordinated Research Project of the same title. Options for application of HTRs for the supply of high temperature process heat for hydrogen generation and other industrial processes are identified and discussed in terms of technical issues and deployment prospects. Use of the HTTR to demonstrate some of the options is discussed including a prioritisation of candidate processes.
IAEA-TECDOC-1235	**Safety aspects of nuclear plants coupled with seawater desalination units** The purpose of this publication is to address the specific safety and licensing aspects of nuclear plants for use in heat utilization applications and to establish the basis for safety assessment of such plants. This publication also proposes a general approach for the preparation of safety requirements for reactors with special safety features or of a smaller size compared with nuclear power plants. This approach (top-down approach) is aimed at generating the safety design requirements for any kind of nuclear reactor starting from those for nuclear power plants, which are covered by the IAEA’s well established corpus of safety standards.
IAEA-TECDOC-1210	**Safety related design and economic aspects of HTGR** This report presents the status of ten country’s individual programmes associated with research, development and commercialisation of the HTGR, and especially identified pathways which can provide the opportunities for international cooperation in realizing the potential of the HTGR.
IAEA-TECDOC-1203	**Thermohydraulic relationships for advanced water cooled reactors** This report has been prepared within the IAEA’s Coordinated Research Project (CRP) on “Thermohydraulic Relationships for Advanced Water Cooled Reactors” which was started in 1995 with the overall goal to promote information exchange and cooperation in establishing a consistent set of thermohydraulic relationships which are appropriate for use in analyzing the performance and safety of advanced water cooled reactors. The CRP participants collaborated to examine the requirements for thermohydraulic relationships and to conduct research and to review experimental data for critical heat flux (CHF), post CHF heat transfer and pressure drop. These relationships are presented in the TECDOC.

Series and No.	Title, Summary
IAEA-TECDOC-1198	**Current status and future development of modular high temperature gas cooled reactor technology** Provides an overview of current modular HTGR technology development activities and power plant design projects among IAEA Member States.
IAEA-TECDOC-1193	**Staffing requirements for future small & medium reactors (SMRs) based on operating experience and projections** Reviews the lessons learned from SMR operation and insights gained from design of new SMRs with a view to optimizing staffing in order to improve overall economics without compromising safety.

2000

Series and No.	Title, Summary
IAEA-TECDOC-1186	**Examining the economics of seawater desalination using the DEEP code** This TECDOC examines in detail the competitiveness of nuclear Seawater desalination. It gives results and interpretations of 500 calculations done with the IAEA software Desalination Economic Evaluation Program (DEEP), and of four independent national studies. Several power options, desalination technologies, plant sizes and economic scenarios were considered.
Computer Manual Series No. 14	**Desalination economic evaluation program (DEEP) user's manual** A comprehensive user's manual for the IAEA software DEEP, available on CD-ROM, version DEEP 2.0. The manual contains installation instructions, gives a brief overview of the technologies included and information and flow-charts on calculation routines used. The appendix "DEEP line by line" explains every equation word in DEEP. NOTE: The IAEA requests all users to establish a license agreement for DEEP.
IAEA-TECDOC-1184	**Status of non-electric nuclear heat applications: Technology and safety** Summarizes the recent activities among Member States presented at a TC meeting in April 1999. The purpose of the meeting was to provide a forum for the exchange of up to date information on the prospect, design, safety and licensing aspects, and development of non-electrical application of nuclear heat for industrial use. This mainly included seawater desalination and hydrogen production.
IAEA-TECDOC-1180	**Unusual occurrences during LMFR operation** Proceedings of a TCM held in Vienna, 9-13 November 1998.
IAEA-TECDOC-1175	**Technologies for improving current and future light water reactor operation and maintenance: Development on the basis of experience** Proceedings of a TCM hosted by the Nuclear Power Engineering Corp. (NUPEC) at Tokyo Electric Power Company's Kashiwazaki-Kariwa site in 1999 that was convened to exchange information on technologies for improving operation and maintenance for current and future LWRs. Topics addressed focus on technologies for improving the economic competitiveness while meeting safety objectives.
IAEA-TECDOC-1172	**Small power and heat generation systems on the basis of propulsion and innovative reactor technologies** Provides the results of presentations and discussions among an international group of experts brought together to review and assess propulsion reactor design features and operational experience, and alternative applications. Proceedings of the AGM held in Obninsk, Russian Federation, 20-24 July 1998.
IAEA-TECDOC-1167	**Guidance for preparing user requirements documents for small and medium reactors and their application** This TECDOC recommends a user requirements document (URD) structure and content outline to support developing countries in preparing their URD for various applications of SMRs.

Series and No.	Title, Summary
IAEA-TECDOC-1163	**Heat transport and afterheat removal for gas cooled reactors under accident conditions** Reports the results of an IAEA CRP conducted to establish sufficient experimental data at realistic conditions and validated analytical tools to confirm the predicted thermal response of modular high temperature gas cooled reactors during accidents.
IAEA-TECDOC-1157	**LMFR core thermohydraulics: status and prospects** Review of data, codes and methodologies for LMFR core thermohydraulic calculations.
IAEA-TECDOC-1155	**Thorium based fuel options for the generation of electricity: Developments in the 1990s.** Review of the current status of the thorium fuel cycles, worldwide applications, economic benefits, and perceived advantages with respect to other nuclear fuel cycles. The results of this updated evaluation are summarized in this publication as a contribution toward documenting past experience.
IAEA-TECDOC-1154	**Irradiation damage in graphite due to fast neutrons in fusion and fission systems** The objective of this report is to summarize the vast amount of information that has been accumulated on graphite from the operation of carbon dioxide and helium cooled reactors and the understandings that have been gained for the use of those concerned with such materials in the future.
IAEA-TECDOC-1149	**Experimental tests and qualification of analytical methods to address thermohydraulic phenomena in advanced water cooled reactors** Proceedings of a Technical Committee Meeting hosted by Paul Scherer Institute in Switzerland in September 1998 convened to review the current status and the future needs in this area.
IAEA-TECDOC-1139	**Transient and accident analysis of a BN-800 type LMFR with near zero void effect** Final report of an international benchmark programme support by the IAEA and EC, 1994-1998.
IAEA-TECDOC-1054	**Technologies for improving the availability and reliability of current and future water cooled nuclear power plants** Proceedings of a Technical Committee Meeting (TCM) held in Argonne, Illinois, USA, 1997. This TCM was convened to identify, review and exchange information on international developments in technologies for achieving high availability and reliability, and to suggest areas where further technical advances could contribute to performance improvement.
TRS-400	**Introduction of nuclear desalination: A guidebook** The report summarizes all the information collected on nuclear desalination and provides guidance on decision-making for deploying nuclear desalination and on the steps for project implementation. The Guidebook comprises three major parts: (1) overview of nuclear desalination; (2) special aspects and consideration relevant to the introduction of nuclear desalination; (3) steps of introduce nuclear desalination. The information contained will be useful for decision makers, policy planners, engineers and scientist in the area of nuclear seawater desalination.

1999

Series and No.	Title, Summary
IAEA-TECDOC-1122	**Fuel cycle option for LWRs and HWRs** Proceeding of a Technical Committee Meeting (TCM) hosted by AECL in Canada, 1998. This TCM provided the opportunity to have in-depth discussion on important technical topics which had been identified in the International Symposium on Nuclear Fuel Cycle and Reactor Strategies: Adjusting to New Realities, that was convened at IAEA headquarters, Vienna, 1997. The main results and conclusions of the TCM were presented as input for discussion at the first meeting of the IAEA's newly formed International Working Group on Fuel Cycle Options.
IAEA-TECDOC-1117	**Evolutionary water cooled reactors: Strategic issues, technologies and economic viability** Proceedings of a Symposium hosted by KEPCO in December 1998.
IAEA-TECDOC-1085	**Hydrogen as an energy carrier and its production by nuclear power** This report was developed under a contract with IAEA. Its documents past activities as well as those currently in progress by many Member States in the development of hydrogen as an energy carrier and its corresponding production through the use of nuclear power.
IAEA-TECDOC-1083	**Status of liquid metal cooled fast reactor technology** Present status report which intends to provide comprehensive and detailed information on LMFR technology with the following topics: experience in construction, fast reactor engineering, reactor physics and safety, core structural material and fuel technology, fast reactor engineering.
IAEA-TECDOC-1060	**LMFR core and heat exchanger thermohydraulic design: former USSR and present Russian approaches.** This document includes the methodology and philosophy of the analytical and experimental investigations in their application to the core and heat exchanger thermohydraulic design of LMFRs.
IAEA-TECDOC-1056	**Nuclear heat applications: Design aspects and operating experience** This publication summarizes the results of the IAEA's activities since the status and international progress made in nuclear application and associated reactor development were reviewed and evaluated in November 1995.

1998

Series and No.	Title, Summary
IAEA-TECDOC-1043	**Technologies for gas cooled reactor decommissioning, fuel storage and waste disposal** Proceedings of a Technical Committee meeting held in Jülich, Germany, 8-11 September 1997.
IAEA-TECDOC-1039	**Influence of high dose irradiation on core structural and fuel materials in advanced reactors** Proceedings of the TCM held in Obninsk, Russian Federation 16-19 June 1997.
IAEA-TECDOC-1020	**Design measures for prevention and mitigation of severe accidents at advanced water cooled reactors** Proceedings of a Technical Committee meeting held in Vienna, October 1996. This TECDOC presents the design features for prevention and mitigation of several accidents of several advanced water cooled reactor designs in a uniform structure which facilitates comparison of the approaches taken for the different designs.
IAEA-TECDOC-1015	**Advances in fast reactor technology** Updated and new information on the status of LMFR development, as reported at the 30th meeting of the International Working Group on Fast Reactors, held in China in May 1997.

Series and No.	Title, Summary
IAEA-TECDOC-999	**Introduction of small and medium reactors in developing countries** Material submitted both by vendor and interested buyer organizations and conclusions drawn from the discussions of these contributions at two Advisory Group meetings on SMR introduction in developing countries.
IAEA-TECDOC-988	**High temperature gas cooled reactors technology development** Proceedings of the TCM on HTGR Technology Development, hosted by the state electric utility of South Africa, ESKOM, in November 1996.
Proceed. Series STI/PUB/1025	**Desalination of sea water using nuclear energy** Proceedings of a symposium held in Taejon, Republic of Korea, May 1997.
Technical Reports Series No. 392	**Design measures to facilitate implementation of safeguards at future water cooled nuclear power plants** Suggestions to reactor designers to result in cost savings for plant operators and for the IAEA.

1997

Series and No.	Title, Summary
IAEA-TECDOC-985	**Accelerator-driven systems: energy generation and transmutation of nuclear waste (status report)** This status report provides an overview of ongoing development activities, different concepts being developed and their project status, as well as typical development trends.
IAEA-TECDOC-984	**Advances in heavy water reactor technology** The IAEA publishes reports on status and progress in HWR design and technology every few years with the goal of presenting balanced and objective information on design and technology advances. This is the third TECDOC in this series. It describes progress in new designs, pressure tube technology, in-service inspection, fuel and fuelling machines and fuel options.
IAEA-TECDOC-917	**Potential for nuclear desalination as a possible source of low cost potable water in North Africa (Arabic version)**
IAEA-TECDOC-898	**Options identification programme for demonstration of nuclear desalination (Arabic version)**
IAEA-TECDOC-978	**Fuel performance and fission product behaviour in gas cooled reactors** Report of a CRP on Validation of Predictive Methods for Fuel and Fission Product Behaviour, which reviewed and documented the status of the experimental database and of the predictive methods for GCR fuel performance and fission product behaviour; and which verified and validated methodologies for the prediction of fuel performance and fission product transport.
IAEA-TECDOC-977	**Integral design concepts of advanced water cooled reactors** The current status of the design, safety and operational issues of integral reactors and recommendations for areas for future development.
IAEA-TECDOC-968	**Status of advanced light water cooled reactor designs: 1996** The IAEA publishes reports on status and progress in LWR design and technology every few years with the goal of presenting balanced and objective information on design and technology advances. This status report presents the rational and basic motivations that lead to a continuing development of nuclear technology, an overview of the world wide status of current LWRs, the present market situation, and desired characteristics for future plants. The report also provides a description of utility requirements that governed the development of new design, the situation with regard to enhanced safety objectives, description of development activities and a presentation of the various reactor designs using a uniform format for their description.

Series and No.	Title, Summary
IAEA-TECDOC-965	**Design approaches for heating reactors** Progress in the development of reactors for supplying low temperature heat, currently of interest for seawater desalination.
IAEA-TECDOC-962	**Small reactors with simplified design** Proceedings of a TCM held in Canada in May 1995 to discuss the status of designs and design requirements related to small reactors for diverse applications.
IAEA-TECDOC-949	**Thermophysical properties of materials for water cooled reactors** Report from a CRP, which collected and systemized a thermophysical properties database for light and heavy water reactor materials under normal operating, transient and accident conditions.
IAEA-TECDOC-948	**Status report on actinide and fission product transmutation studies** An up-to-date general overview of current and planned research on transmutation.
IAEA-TECDOC-946	**Acoustic signal processing for the detection of sodium boiling or sodium-water reactions in liquid metal fast reactors** A summary of the work performed under a CRP carried out from 1990 to 1995. It was the continuation of an earlier CRP entitled Signal Processing Techniques for Sodium Boiling Noise Detection (1984-1989).
IAEA-TECDOC-942	**Thermodynamic and economic evaluation of co-production plants for electricity and potable water** The IAEA carried out a study to establish methodologies for allocating costs to the two final products of co-production plants based on thermodynamic criteria and to enable economic ranking of co-production plant alternatives. This publication describes methodologies and presents the results obtained from analysing a reference case.
IAEA-TECDOC-940	**Floating nuclear energy plants for seawater desalination** Proceedings of a TCM on Floating Nuclear Plants for Seawater Desalination, held in the Russian Federation in May 1995.
IAEA-TECDOC-936	**Terms for describing new, advanced nuclear power plants** The development of new nuclear power plant designs spans a wide range of alternatives. Some represent only small extensions of existing designs, while others incorporate more significant modifications and departures for such designs. This report presents a precise explanation of the terms used, to avoid inconsistencies.
IAEA-TECDOC-933	**Creep-fatigue damage rules for advanced fast reactor design** Proceedings of a TCM held in Manchester, United Kingdom, 11-13 June 1996.
IAEA-TECDOC-923	**Non-electric applications of nuclear energy** Proceedings from the AGM on non-electric applications of nuclear energy held in Indonesia in November 1995, which reviewed and assessed the present status and recent progress made in systems and processes for nuclear heat applications and associated reactor development.
IAEA-Computer Manual Series No. 12	**Methodology for economic evaluation of cogeneration/desalination options: A user's manual** Between 1992 and 1994 the IAEA provided assistance to five North African countries to investigate site-specific applications of nuclear energy for desalination. This manual is designed to facilitate workshops and provide the user with instructions for use and interpretation of a spreadsheet methodology that models many types of nuclear/fossil electric power and heat sources of varying sizes depending on site specific demands.

1996

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IAEA-TECDOC-920	**Technical feasibility and reliability of passive safety systems for nuclear power plants** Proceedings of an AGM held in Jülich, Germany, 21-24 November 1994.
IAEA-TECDOC-917	**Feasibility study of nuclear desalination as a possible source of low-cost potable water in North Africa** An assessment of the regional specific aspects, the available technical options, cost evaluation of various technical options for the production of desalted water, and the necessary steps to needed ensure the successful implementation of a nuclear desalination programme.
IAEA-TECDOC-916	**Advanced fuels with reduced actinide generation** Discusses reducing the amount of actinides which have already been generated and the use of the thorium cycle in which the problem of undesirable actinides is largely eliminated.
IAEA-TECDOC-908	**Fast reactor fuel failures and steam generator leaks: transient and accident analysis approaches** A survey of activities on transient and accident analysis for LMFRs.
IAEA-TECDOC-907	**Conceptual design of advanced fast reactors** Proceedings of a TCM held in Kalpakkam, India, 3-6 October 1995.
IAEA-TECDOC-901	**Graphite moderator lifecycle behaviour** Proceedings from the Specialists Meeting held in the United Kingdom in September 1995. Topics included: operation and safety procedures for existing and future graphite moderated reactors; graphite testing techniques; neutron irradiation and oxidizing conditions effects on key graphite properties; and decommissioning.
IAEA-TECDOC-899	**Design and development of gas cooled reactors with closed cycle gas turbines** Proceedings of a TCM and Workshop on the status of design activities and technology development in national HTGR programmes with specific emphasis on the closed cycle gas turbine, and opportunities for international cooperation in the development of this concept.
IAEA-TECDOC-898	**Options identification programme for demonstration of nuclear desalination** Provides a perspective how to proceed with demonstration of nuclear desalination, based on the work of a Working Group which resulted in identification of a few practical options, based on reactor and desalination technologies which are readily available without further development being required at the time of demonstration.
IAEA-TECDOC-887	**In-core fuel management benchmarks for PHWRs** Provides reference cases for the verification of code packages used for reactor physics and fuel management of PHWRs.
IAEA-TECDOC-884	**Absorber materials control rods and designs of shutdown systems for advanced liquid metal fast reactors** Proceedings of a TCM held in Obninsk, Russian Federation, 3-7 July 1995.
IAEA-TECDOC-882	**Intercomparison of liquid metal fast reactor seismic analysis codes. Vol. 3: Comparison of experimental results with computer predictions for reactor cores.** Report of a CRP on benchmark analysis of computer codes against experimental data.
IAEA-TECDOC-881	**Design and development status of small and medium reactor systems 1995** Material submitted by different vendors and organizations and conclusions drawn from the discussion of these contributions at a number of consultants meetings and an Advisory Group meeting. It provides a balanced review of the current discussion on SMR potential, a review of the economic market and financial aspects of such systems, and highlights of the incentives for the developments, as well as the main objectives and requirements currently under discussion in many Member States.
IAEA-TECDOC-876	**Progress in liquid metal fast reactor technology** Proceedings of the 28th meeting of the IWG on Fast Reactors, held in Vienna, 9-11 May 1995.

Series and No.	Title, Summary
IAEA-TECDOC-872	**Progress in design, research and development and testing of safety systems for advances water cooled reactors** Proceedings of a Technical Committee Meeting convened in Italy, 1995 to review progress in design, research and development and testing of safety systems for advanced water-cooled reactors.
IAEA-TECDOC-866	**Fast reactor database** Detailed data on liquid metal cooled fast reactors - specifically plant parameters and design details. Each LMFR power plant is characterized by about 400 parameters, by design data and by relevant materials.
IAEA-TECDOC-861	**Review of design approaches of advanced pressurized LWRs** A comparative review of design approaches of advanced pressurized light water cooled reactor designs, with contributions from different vendors and conclusions from the IAEA TCM and Workshop convened in the Russian Federation in May 1994.
IAEA-TECDOC-858	**Safe core management with burnable absorbers in WWERs** State of the art information on burnable poisoned fuel based on experimental evidence and on the utilization of theoretical models designed to help achieve improvements in safety and economy of LWR cores with hexagonal geometries.

1995

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IAEA-TECDOC-849	**In-core fuel management code package validation for BWRs** (see IAEA-TECDOC-815)
IAEA-TECDOC-847	**In-core fuel management code package validation for WWERs** (see IAEA-TECDOC-815)
IAEA-TECDOC-829	**Intercomparison of liquid metal fast reactor seismic analysis codes. Vol.2: Verifications and improvements of reactor core seismic analysis codes using core mock-up experiments** Report of a series of specialists meetings, consultancies and an RCM related to a CRP on Intercomparison of LMFR Seismic Analysis Codes.
IAEA-TECDOC-819	**Earthquakes: Isolation, energy dissipation and control of vibrations of structures for nuclear and industrial facilities and buildings** Summarizes the contributions to the International Seminar on Isolation, Energy Dissipation and Control of Vibrations of Structures. The seminar addressed the development and application of innovative techniques that have been developed for the abatement of seismic vibrations of structures and covered floor isolation, passive energy dissipation and active control of vibrations.
IAEA-TECDOC-817	**Influence of low dose irradiation on the design criteria of fixed internals in fast reactors** Report of the fourth meeting of the IWGFR devoted to mechanical properties of LMFR structural materials.
IAEA-TECDOC-816	**In-core fuel management: Reloading techniques** Report of a TCM and Workshop on In-core Fuel Management - Reloading Techniques, held in Vienna in October 1992, which covered computer code descriptions, methodologies and experiences of utilities and vendors for nuclear fuel reloading, as well as optimisation techniques for reloading, and expert system codes.

Series and No.	Title, Summary
IAEA-TECDOC-815	**In-core fuel management code package validation for PWRs** A CRP was set up to obtain well defined cases for the verification of code packages for PWRs, BWRs and WWERs. Because of the significant differences in core layout and core management of these reactor types, the CRP was performed in three separate parts (see also IAEA-TECDOCs 847, 849).
IAEA-TECDOC-798	**Intercomparison of liquid metal fast reactor seismic analysis codes. Vol. 1: Validation of seismic analysis codes using reactor core experiments** Report of a series of specialists meetings, consultancies and an RCM related to a CRP on Intercomparison of LMFR Seismic Analysis Codes.
IAEA-TECDOC-791	**Status of liquid metal fast reactor development** Updated and new information on the status of fast reactor development and on activities in the field of advanced nuclear power technology during 1993, as reported at the 27th meeting of the International Working Group on Fast Reactors, held in Vienna in May 1994.
IAEA-TECDOC-784	**Response of fuel, fuel elements and gas cooled reactor cores under accidental air or water ingress conditions** Report of a TCM on Response of Fuel, Fuel Elements and Gas Cooled Reactor Cores under Accidental Air or Water Ingress Conditions, held in China in October 1993, which concluded that plant safety is not compromised for design basis accidents, and continued efforts to validate the predictive methods against experimental data are worthwhile.

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