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Nuclear Power Technology Development Section

IAEA
International Atomic Energy Agency
Atoms For Peace

With advice from representatives of Member States, the Nuclear Power Technology Development Section (NPTDS) fosters information exchange and co-operation in the area of advanced nuclear energy technologies needed to meet, in a sustainable manner, the increasing energy demand of the 21st century.

NPTDS collects, analyzes and provides, through publication of status reports and other technical documents, balanced and objective information to all Member States on technology status and development trends for current and future reactor systems and their applications.

NPTDS provides a global forum for experts from Member States to exchange information on technology advances and development needs, and to establish and carry out collaborative research and development projects for improving economics, reliability, availability and safety of current and future nuclear power plants.

The activities of the NPTDS assist Member States considering implementation of nuclear power programmes, as well as those with existing programmes, to maintain current awareness of advances in nuclear power technology.

Postal Address:
International Atomic Energy Agency
Nuclear Power Technology Development Section
Wagramer Strasse 5, P.O. Box 100,
A-1400 Vienna, Austria

Requests for information may be addressed directly to:
Office of NPTDS
Telephone: + 43 1 2600 22817
Facsimile: + 43 1 26007
e-mail: official.mail@iaea.org

NUCLEAR POWER TECHNOLOGY DEVELOPMENT SECTION (NPTDS)

Why NPTDS exists

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."

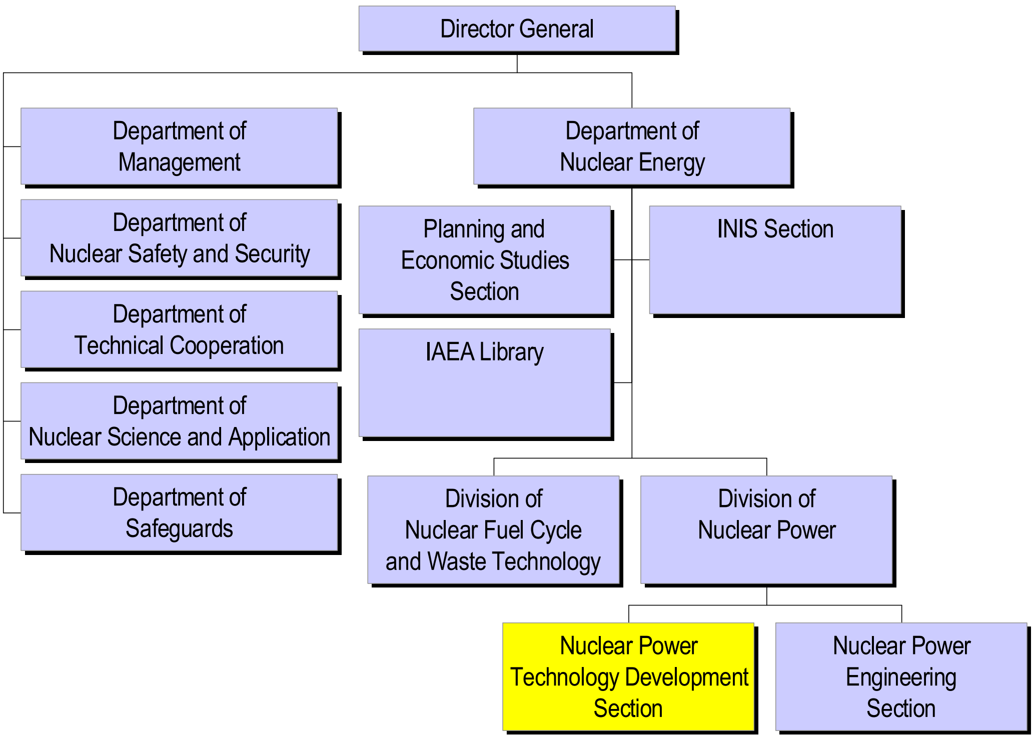
Today, global environmental change, and the continuing increase in global energy supply required to provide increasing populations with an improving standard of living, make these functions, first implemented when the Statute came into force in 1957, even more relevant.

Nuclear energy, which has demonstrated excellent technical and economical performance in many countries, can play an important and increasing role in global energy supply.

To meet the competitive challenge in the decades ahead, a new generation of advanced reactor systems is being developed. Current estimates exceed 2 billion USD annually for R&D by the nuclear industry and Governments for both evolutionary and innovative designs. Evolutionary designs require moderate development efforts mainly through modifying proven features while innovative designs call for substantial development efforts as well as pilot or demonstration plants.

NPTDS exists to foster the global realization and sharing of the benefits of the technology advances in nuclear energy by facilitating international information exchange and co-operation. Consistent with the IAEA Statute, NPTDS provides balanced, objective information to all Member States on technology status and development trends for current and future reactor systems and a global forum for experts from Member States to exchange information on technology advances and development needs, and to establish and carry out co-operative research projects.

Where NPTDS fits[1]



1 reflecting the organizational structure as of September 2003

How NPTDS ensures that its work is relevant

On selected topics, NPTDS periodically informs the IAEA's Board of Governors and General Conference, and incorporates feedback into its programmes. To ensure that its work fully reflects the interests of Member States, the Section has established Technical Working Groups (TWGs) for each major reactor type, and the International Nuclear Desalination Advisory Group (INDAG).

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 co-ordination with their programmes.

The standing technical working groups meet every one to two years and provide recommendations on formulating the IAEA's programmes and 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 technical working group members.

The scope of the 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 elsewhere within the IAEA, for example within the frameworks of the TWG on Nuclear Power Plant Control and Instrumentation (TWG-NPPCI), the TWG on Water Reactor Fuel Performance and Technology (TWG-FPT), and the TWG on Life Management of Nuclear Power Plants (TWG-LMNPP). The Section keeps abreast of such work to avoid unproductive overlap, and coordinates activities with other IAEA projects, and with related activities of other international organizations where appropriate.

What the Section does

Activities conducted within the Section make use of established mechanisms. Technical Meetings are convened to review progress on selected technology areas in which there is a mutual interest. For broader topics, Symposia or Conferences are held. Co-operation with non-IAEA meetings is undertaken when topics are closely related to the Section's programme and are of interest to several Member States. Activities are not included that would otherwise be conducted by organizations in Member States on a commercial basis.

Co-operative research is performed through co-ordinated research projects (CRPs), typically 3 to 5 years in duration, which often involve experimental activities (see pages 19-20).

Periodic status reports are produced that provide information about the state-of-the-art, recent results achieved and trends in technology development programmes in Member States. These status 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. Status reports and other NPTDS publications are listed in pages 21-32.

The Section conducts two sub-programmes (A.3 and A.4) consisting of six projects, as listed in the IAEA's 2004 - 2005 Programme and Budget:

A.3 Co-ordination of International Collaboration for the Development of Innovative Nuclear Technology

A.3.1. Co-ordination of Agency activities for innovative nuclear technology

A.3.2. Co-ordination of international collaborative R&D for innovative nuclear technology

A.4 Technology Developments and Applications for Advanced Reactors

A.4.1. Technology advances in water cooled reactors for improvement in economics and safety

A.4.2. Technology advances in fast reactors and accelerator driven systems (ADS)

A.4.3. Technology advances for gas cooled reactors

A.4.4. Support for demonstration of nuclear seawater desalination

SMALL AND MEDIUM REACTORS[2]

In operation[3]	144
Under construction	12
Number of countries with SMRs	29
Generating capacity, GW(e)	61.7
Operating experience, reactor-years	5198

China's HTR-10, a 10 MW test high temperature reactor located at the INET Institute near Beijing, is currently undergoing safety demonstration tests and will be coupled to a gas turbine. First criticality was achieved in Dec. 2000. This plant will be utilized to evaluate a wide range of nuclear power applications including electricity production, steam and district heat generation, and high temperature industrial processes. *(Credit: INET)*

In the early decades, civil nuclear power essentially borrowed from the experience of reactors for nuclear submarines, which came first and were essentially small-capacity reactors. In 1970's, the major focus for nuclear power was on the design and construction of nuclear plants of increasing size, with average size leveling out at about 1000 MWe with a tendency for further increase. This was and is generally appropriate for many industrialized countries, which could add generation capability to their electrical grids in larger increments and benefit from the construction costs reduced due to scale factor. However, it is not appropriate for many developing countries that have small electric grids, limited capacity for investment or small turnover of capital in the electricity market.

Even the largest electric grids experienced problems with excess capacity in the 80's and 90's. In the near future some countries may face lack of sites that are appropriate for further construction of large-capacity plants. For some overpopulated developing countries new employment opportunities are created through the multiplicity of plants, which increases upon the reduction of unit power. Finally, new technologies cannot be deployed at once to a large scale. Learning from a small prototype plant may be a necessary step in reaching the final goal of wide-scale deployment of an innovative technology.

For reasons mentioned above, starting from 1980's there has been an increasing emphasis on the development of small and medium sized reactors (SMRs) - up to about 700 MWe. Also, it turned out that SMRs are of particular interest for advanced future non-electric applications, such as hydrogen production, coal liquefaction and other process heat applications. Some examples are listed below:

PBMR (Pty) Ltd, an international consortium from South Africa and the United Kingdom is pursuing a Pebble Bed Modular Reactor (PBMR) project to develop a gas cooled reactor (~120 MWe) utilizing fuel and systems developed in Germany and a closed cycle gas turbine.

In Argentina, the construction of a small 25 MWe prototype reactor (CAREM) with an integral steam generator that could be coupled to a desalination process was approved and site selection process is underway.

Other activities on development of LWRs of integral design are being carried out in the Republic of Korea for the 330 MWth SMART design, in Russia for the VK-300, VPBER-600, VBER-300, and ABV6M and in the U.S. for the IRIS modular LWR that emphasizes proliferation resistance through features to facilitate safeguards (e.g. a core life of 8 years). Conceptual and basic designs for Russian VK-300 seawater desalination/electricity co-generation plant have been completed, and there are plans to construct it at the Arkhangelsk site starting from 2010. In the Republic of Korea, conceptual design has been completed and basic design is underway for a 65 MWth prototype plant for the SMART reactor. The target for obtaining a construction permit is June 2005.

Japan operating a 30 MWth gas cooled high temperature test reactor (HTTR), which uses prismatic fuel. It is also studying multiple concepts and applications of evolutionary and innovative SMRs with light-water, sodium and lead-bismuth coolants.

In China, the Institute for Nuclear Energy Technology near Beijing has developed an integral PWR of 200MWth, called the NHR-200, for desalination and district heat, as well as a 10 MW high temperature test reactor (HTR-10). The China Experimental Fast Reactor (CEFR) of 25 MWe is under construction.

India is developing a conceptual design of the 300 MWe AHWR co-generation plant to make efficient use of the thorium ores present in the country and later on to couple it with the Fast Reactor programme. It is also studying an option of a lead-bismuth cooled compact core reactor of 100 KWth.

The United States, Russia, France and Japan are working on the preliminary design of the 284 MWe Gas-Turbine Modular Helium Reactor (GT-MHR), using a prismatic block fuel design developed in the US. The concept is being designed for plutonium consumption with planned subsequent commercial application for electricity and heat production.

Russia is progressing with barge-mounted versions of several small sized reactors formerly used in marine reactors for electricity as well as heat generation and

2 include all reactors up to about 700 MWe

3 reactor data presented in this Brochure are results as of September 2003 and are derived from the IAEA's Power Reactor Information System

seawater desalination considering their use in northern parts of Siberia. Such reactors are factory fabricated and fuelled and could be eventually returned to the supplier. Some of them are developed as modules to be serially produced for larger capacity plants.

The U.S. DOE initiated Generation IV International Forum (GIF) initiative is an international project directed toward deployment of innovative reactors in the next 25-40 years. Out of the 6 nuclear energy systems selected for further R&D only 2 make no provisions for the reactors that fit into SMR range.

Particular R&D activities are ongoing in the U.S., Japan, Russian Federation, the Republic of Korea, India, China, South Africa, Argentina and other countries for more than 50 concepts of innovative SMRs.

With these developments in mind, the IAEA's Nuclear Power Technology Development Section has initiated the preparation of a Status Report on Innovative SMR Designs and of a Report on Small Reactors without On-site Fuelling. In view of some experts, the latter may offer a very attractive solution for cost-effective implementation of safeguards in scenario of large-scale global deployment of nuclear energy. Both reports will use new common outline for SMR design descriptions, which makes provision for the design features that facilitate reactor performance in all areas accepted as critical for future deployment of nuclear power and possible applications, makes a link to fuel cycle options, and outlines the enabling technologies that may be common for SMRs of different types. Both reports will be issued as TECDOCs in 2005.

GAS COOLED REACTORS

www.iaea.org/htgr

JAERI's HTTR 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. ***(Credit: JAERI)***

Worldwide, there are currently 28 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	26
Under construction	0
Test Reactor in operations	2
Number of countries with GCRs	3
Generating capacity, GW(e)	10.86
Operating experience, reactor-years	1565

Several Member States have research and development programmes related to 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 coupling of a gas turbine to a HTGR, resulting in a net plant efficiency higher than 40%. In addition to electricity generation, HTGR designs are also well placed for co-generation of process heat, promising even higher thermal efficiency. Potential non-electric applications include high-temperature process heat applications such as Hydrogen production and low-temperature process heat applications such as seawater desalination and district heating.

Major GCR activities are conducted within the framework of 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 a coordinated research project (CRP) on HTGR performance evaluation, which focuses on core phycis and thermal-hydraulics benchmarking, and another on advances in HTGR fuel technology. In addition, conferences, topical meetings, and training workshops are occasionally organized to facilitate information exchange. HTGR activities in Member States include:

Members of the TWG-GCR, established in 1978

Austria	Turkey
China	The Netherlands
France	The Russian Federation
Germany	South Africa
Italy	United Kingdom
Indonesia	United States of America
Japan	European Commission
Poland	OECD/NEA

In China, initial criticality of a 10 MW(th) High Temperature Reactor for non-electric applications was achieved in 2000, and power ascension testing is proceeding.

In Japan, a 30 MW(th) High Temperature Engineering Test Reactor (HTTR) began operation in 1998 with process heat applications for hydrogen production in mind.

Russia, USA, France and Japan have been cooperating on the development of a 284 MW(e) Gas Turbine Modular Helium Reactor (GT-MHR) as a Plutonium burner.

PBMR of South Africa is still pursuing the development of a 168 MW(e) Pebble Bed Modular Reactor (PBMR) which has evolved from a German design developed in the 1980s.

The European Commission also has been conducting a substantial programme for the development of modular HTGR technology and advanced HTGR fuel qualification, within the 5th Framework programme. The OECD/NEA is addressing basic research in HTR technology and the nuclear production of hydrogen. These activities are being carried out in cooperation and coordination with the IAEA activities.

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 co-operation. The tasks 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	Germany	Spain
Belgium	India	Sweden
China	Italy	Switzerland
Czech Republic	Japan	United Kingdom
Finland	Republic of Korea	United States of America
France	The Russian Federation	OECD-NEA
		European Commission

Members of the TWG-HWR, established in 1997

Argentina	Republic of Korea
Canada	Pakistan
China	Romania
India	The 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 and capabilities of the Agency, including expertise in the Nuclear Power Engineering Section and the Planning and Economic Studies Section of the Department of Nuclear Energy, and in the Division of Nuclear Installation Safety of the Department of Nuclear Safety and Security.

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. in 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 co-ordinate 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 co-ordinated 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 new CRP is underway 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, reviewed 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	356
Under construction	23
Number of countries with LWRs	27
Generating capacity, GW(e)	317
Operating experience, reactor-years	8090

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

In the Republic of Korea, the benefits of standardization and construction in series are being realized with the 1000 MW(e) Korean Standard Nuclear Plant (KSNP) units. The accumulated experience is being used by KHNP to develop the KSNP$^+$. The first KSNP$^+$ units are planned for construction at Shin-Kori unit-1 and 2. Furthermore, 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. Recent development of the APR-1400 focused on improving availability and reducing costs. A power level of 1400 MW(e) has been selected to capture economies-of-scale. The first APR-1400 units are planned for Shin-Kori 3 and 4.

Tokyo Electric Power Company's Kashiwazaki-Kariwa Units 6&7 Two 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)*

Benefits of standardization and construction in series are also being realized in Japan with the ABWR units[4]. Future ABWRs are expected to achieve a significant reduction in generation costs 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 cost relative to a standardized ABWR. The power level of ABWR-II has been increased to 1700 MW(e), 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 1530 MW(e) advanced PWR has been completed by Mitsubishi Heavy Industries and Westinghouse for the Japan Atomic Power Company's Tsuruga-3 and –4 units.

In France and Germany, Framatome ANP has designed the 1545 MW(e) 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. 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. Also, Electricite de France is planning to construct an EPR in France.

Artist's concept of the EPR for Olkiluoto-3 in Finland

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

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. WWER-1000 units are under construction in China, India and the Islamic Republic of Iran. The basic design of a 1500 MWe WWER, scaled-up from the advanced WWER-1000/V-392 design, is now under development by Atomenergoproject and Gidropress to capture the economy-of-scale. The first 1500 MWe unit is planned for commissioning at Leningrad NPP by the year 2012. Development is also on-going on a mid-size WWER-640 with passive safety systems, and on an integral design with the steam generator system inside the reactor pressure vessel.

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 were certified in December 1999. Efforts are currently underway by Westinghouse on a 1090 MW(e) plant called the "AP-1000" applying the passive safety technology developed for the AP-600 with the goal to reduce the capital costs through economies-of-scale. The AP-1000 design is under review by the U.S. NRC for design certification. General Electric is also designing a 1380

[4] The first two ABWRs in Japan, Kashiwazaki-Kariwa 6 and 7 have been in commercial operation since 1996 and 1997 respectively. Also in Japan, two ABWRs (Hamaoka unit 5 and Shika unit 2) are under construction and eight more are in the planning stage). Two ABWRs are under construction in Taiwan, China.

MW(e) 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 670 MW(e) simplified BWR with passive systems. The ESBWR is under pre-application review by the U.S NRC for design certification.

In China, the China National Nuclear Corporation (CNNC) is developing the CNP-1000 plant, which incorporates feedback of experiences of design, construction and operation of Qinshan and the Daya Bay NPPs.

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 super-critical regime (above 22.4 MPa and 374 C), and would achieve a higher thermal efficiency than current water-cooled reactors.

A report on Status of Advanced LWR Designs: 2004 has recently been published.

Heavy Water Moderated Reactors

In operation	35
Under construction	9
Number of countries with HWRs	7
Generating capacity, GW(e)	17.1
Operating experience, reactor-years	795

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.

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

In China, the Qinshan CANDU project, a partnership between AECL, Canada and the Third Qinshan Nuclear Power Company (TQNPC), has proceeded successfully since construction began in June 1996. This multinational endeavour uses the combined expertise of companies from Canada, China, Japan, the Republic of Korea, and the USA to build two 700MW(e) CANDU 6 units. Qinshan Unit 1 began commercial operation 2002 December 31, after a 54 month construction period. Unit 2 went into service in July 2003.

Qinshan, China - HWR open top construction – insertion of steam generators. ***(Credit AECL)***

In Canada, AECL is adapting the basic CANDU design to develop the Advanced CANDU 700 MWe Reactor (ACR-700), focusing on improvements in economics, inherent safety characteristics and performance, while retaining the features of the earlier family of HWR nuclear power plants. The unit size has been selected to match the requirements, in increasingly deregulated electrical power markets, for plants with lower plant capital and operating costs, plus reduced project schedules, through the use of improved design and construction methods and operational improvements. However, the basic concept is suitable for a range of plant sizes with electrical outputs in the range of 400 MWe to 1200 MWe. The design is optimised 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 continuing process of evolution of HWR design has been carried out since the Rajasthan 1 and 2 projects. In 2000 construction began on two 540 MWe units at Tarapur which incorporate feedback from the indigenously designed 220 MWe units[5]. Furthermore, design activities are underway for 700 MWe plants.

India is also 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 cooperative research project on intercomparison of techniques for pressure tube inspection and

[5] The most recent plants in this series, the 220 MWe Kaiga-1 and –2 and the Rajasthan-3 and –4 units, began commercial operation in the year 2000.

diagnostics is nearing completion. An international standard problem exercise on intercomparison and validation of computer codes for HWR thermalhydraulics safety analyseshas recently been completed.

A Technical Report Series document on "Heavy Water Reactors, Status and Projected Developments" that presents 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. A document entitled "User Requirements for Heavy Water Reactors" is in preparation.

Technology Advances in Fast Reactors and Accelerator Driven Systems

http://www.iaea.org/inis/aws/fnss/index.html

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 sea water desalination in the world (BN-350 in Kazakhstan, which was commissioned in 1964, generated first electricity in 1973, and was shut down in 1998).


Chinese Experimental Fast Reactor (CEFR) under construction, 2004. ***(Credit: CIAE)***

In China, the 25 MW(e) China Experimental Fast Reactor (CEFR) is under construction, as the first step in the Chinese FR engineering development. Ninety percent of the concrete constructions, including the main building, have been completed. About 300 hundred components have been installed in the building. First criticality is foreseen in 2008.

As a second step in the Chinese FR technology development effort, a 600 MW(e) China Prototype Fast Reactor (CPFR)is presently under consideration. The role of minor actinide transmutation is also being evaluated taking as reference the CPFR.

Liquid Metal Fast Reactors

In operation	3
Under construction	0
Number of countries with FRs	3 (+1 with a test reactor)
Generating capacity, GW(e)	1.039
Operating experience, reactor-years	155

In France, decommissioning work that started in 1999 is underway at the Superphénix FR. The last fuel subassembly has been unloaded on 19 March 2003. At Phénix, after completion of the plant renovation programme, power operation was resumed on 15 June 2003. The reactor will be operated for 6 irradiation cycles of 120 EFPD each. Its main mission will be 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 wastes management. As regards R&D, CEA has launched a comprehensive R&D program to study promising (with regard to enhanced safety characteristics, sustainability and economics) technologies for future nuclear energy systems. The reference system is based on a gas cooled FR with on-site closed fuel cycle. However, many of the long-term options investigated are believed to be of generic interest, and to offer the chance of developing high performance fuels and materials. The construction of a limited power experimental gas cooled fast reactor is foreseen by 2015.

In India, the detailed design, R&D, manufacturing technology, and safety review for the 500 MW(e) Prototype Fast Breeder Reactor (PFBR) were continued. Excavation works at the site have been completed. Purchase orders have been placed for important long delivery mechanical components, and work order for nuclear buildings has been issued. R&D in reactor physics, engineering development, structural mechanics, metallurgy, non-destructive evaluation, chemistry and reprocessing was continued. Important works include PFBR shielding experiments, testing of transfer arm in air, boron enrichment, post-irradiation examination of FBTR fuel after 100 GWd/t burn-up, structural integrity testing, and reprocessing of FBTR carbide fuel. The small-size Fast Breeder Test Reactor (FBTR), located at Kalpakkam and used for various test irradiations, attained peak burn-up of 123 GWd/t.

In Japan, the direction of the R&D efforts in the field of fast breeder reactor (FBR) 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 commercialisation stage of this technology. The first phase of the "Feasibility Study on Commercialised Fast Reactor Cycle Systems" was completed in March 2001. The three-year period extending over the fiscal years 2001 through

2003 constitutes the initial term of the second phase. During this term, research activities were focused on the design of the concepts, and on the fundamental tests of the key technologies. The interim evaluation has been completed for the combinations of several of these concepts, and the feasible candidates concepts are identified, together with crucial R&D items, and have been summarized as a road map for the key technology development for each candidate. An interim summary of these activities will be checked and reviewed, and, based on the results, the research for the fiscal years 2004 through 2005 will be conducted with the objective of clarifying the promising concepts for the fast reactor cycle. The 280 MW(e) prototype fast breeder reactor MONJU remains shutdown after a sodium leakage accident in the secondary heat transport system that occurred in December 1995 during the 40% power pre-operational testing phase. Considerable effort has been put into activities aiming at regaining public understanding and acceptance. In December 2002, the Minister of Economy, Trade and Industry (METI) granted the permission for safety licensing examination related to the countermeasures against sodium leaks in MONJU. However, the Nagoya high court - Kanazawa branch rendered a negative judgment of the Administrative Suit on 27 January 2003. METI appealed to the Supreme Court. The Advisory Committee on MONJU Safety of the Fukui Prefecture, which had been established on 19 July 2001, finished its deliberations after 19 meetings on 10 November 2003, and submitted its final report on 14 November 2003: The conclusion is that MONJU was a sufficiently safe facility from the engineering viewpoint, once the plant improvements proposed by JNC are implemented. METI granted on 30 January 2004 the approval for the MONJU detailed "design and construction procedure" of the plant improvement. The government of Japan and JNC are making every effort, including international cooperation, towards the restart of MONJU. The experimental fast reactor JOYO has successfully completed and tested the plant and core modifications for the MK-III upgrade program, and rated power operation is planned to start in May 2004. The upgraded MK-III core provides a significantly enhanced irradiation testing capability compared to the MK-II core. Initial critically of the MK-III core was achieved on 2 July 2003, which was followed by the successful operational demonstration up to the rated thermal power of 140 MW. Functional and performance testing verified the design parameters. The pre-service inspection by the Ministry of Education, Culture, Sports, Science and technology (MEXT) was completed on 27 November 2003. A utilization plan for future fuels and materials developments and safety testing in the JOYO MK-III core has been developed.

In the Republic of Kazakhstan, the fast breeder reactor BN-350 was commissioned in November 1972 and finally shut down in April 1999. The General Plan for the BN-350 decommissioning was developed within the framework of a Kazakh – US project. At the end of March 2003, the Plan was presented for final review to a IAEA group of experts. The project EAGLE is under way since 2000 under a contract between the National Nuclear Centre of Kazakhstan RK and Japan Nuclear Cycle Development Institute. 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 Korea Atomic Energy Research Institute (KAERI) has been developing KALIMER (Korea Advanced LIquid MEtal Reactor), a pool-type liquid metal-cooled reactor, under a national long-term R&D program. From 2002-2004, basic key technologies and the advanced concepts of KALIMER-600 with a rating of 600 MW(e) are being developed. During this period, effort are made to establish advanced concepts with emphasis on proliferation-resistant core design, and on the enhancement of economics and safety. In 2003, the preliminary KALIMER-600 design concept was established [600 MW(e) core without blankets, but maintaining the capability of transuranics (TRU) self-recycling], and several experiments were performed for the validation of computer codes and models. From the evaluation of the reactor vessel size and decay heat removal capacity, the Passive safety Decay Heat Removal System (PDRC) that is based on the natural circulation of sodium and air was retained as the most favourable passive design concept. Also in 2003, a conceptual study on ultra-long life cores with power densities higher than the conventional ones was finished. This concept, which adopts a DUPIC-like fuel fabrication process, was pursued as an option for enhanced proliferation resistance. Finally, as part of reactor design studies, the preliminary design of a 900 MW(t) lead-cooled, breakeven, TRU burner core has also been developed in 2003.

In Russia, based on its successful experience with FRs such as the BR-10, BOR-60 and BN-600 (April 8, 2004 marked the 24th anniversary of the first power production with BN-600), work continues on an already licensed 800 MW(e) BN-800 that can use civilian and ex-weapons plutonium. According to the revised "Programme for Nuclear Power Development in the Russian Federation for the Period 1998-2005, and for the Period Until 2010", the start-up of BN-800 at the Beloyarsk site is scheduled for 2010. Further activities in the FR area in Russia include: (a) justification of a hybrid, as well as full MOX core design for BN-600 to incinerate weapons-grade plutonium; (b) justification of life extensions for BN-600; (c) review of the BN-800 reactor design to reduce construction costs; (d) design of the BOR-60 reactor modification, including its replacement by the BOR-60M reactor; (e) development of advanced and innovative FR designs with enhanced safety [large sodium cooled FR with mixed oxide fuel, two circuit reactor concepts with sodium coolant and gas-turbine cycle (both large size reactors, in the 1200-1600 MW(e) range, and small/medium size modular and transportable co-generation reactors up to 300 MW(e)), FR with supercritical water cooling, BREST-300 lead cooled demonstration FR with nitride fuel, and lead-bismuth eutectic cooled SVBR-75/100 reactor], including experimental support studies.

In the UK, there is no government sponsored FR R&D programme, except for the UKAEA PFR decommissioning work at Dounreay. However, a small BNFL-funded FR R&D programme involving BNFL/NNC/AEA Technology is pursued in the following fields: knowledge preservation; CAPRA-CADRA European collaboration; EU fifth and sixth Framework Programme activities; and collaboration with Japanese research organizations. The CAPRA-CADRA collaboration with France, Germany, and Belgium covers reactor systems for plutonium and minor actinides burning sodium cooled FRs. Recently, emphasis is shifting to gas cooled FRs and to accelerator driven system (ADS) analyses. The UK is contributing to core design, thermal hydraulics design, and fuel design and performance of various FR and ADS concepts. As regards knowledge preservation activities, NNC is maintaining and adding to an archive database of historical FR papers. The aim of this activities is to ensure future retention/accessibility of FR historical information. As regards PFR decommissioning, both the sodium and caesium removal plants are in the commissioning phase. The demonstration of full throughput with inactive sodium was achieved in 2001.

In the U.S, there have been substantial activities in continuing the development of technologies related to advanced nuclear energy systems, including advanced fuel cycles, fast reactors and transmutation. The two main programs that cover the relevant activities in advanced fuel cycles and reactors are the Advanced Fuel Cycle Initiative (AFCI), and the Generation IV Nuclear Energy Systems program. The Generation IV program and AFCI are being closely coordinated with the combined objective of enabling a long term future for nuclear power contributions to energy needs, while allowing for a manageable transition in the U.S. from the current fuel cycle to fuel cycles that can support the sustainable deployment of nuclear capacity and meet waste management constrains. The broader program includes, in addition to the AFCI and Generation IV, the Nuclear Hydrogen Initiative (NHI), to develop hydrogen production systems and coupling them to nuclear heat sources. The primary focus of the hydrogen production is in the Next Generation Nuclear Plant (NGNP), a very high temperature gas-cooled thermal reactor. The Generation IV, NHI and AFCI programs are working together to develop the next generation of nuclear systems by (a) developing and demonstrating advanced nuclear energy systems that meet future needs for safe, sustainable, environmentally responsible, economical, proliferation-resistant, and physically secure energy, and (b) developing and demonstrating technologies that enable the transition to a stable, long term, environmentally, economically, and politically acceptable advanced fuel cycle. The Nuclear Energy Research Initiative (NERI) programs (domestic and international) are being emphasized, but as part of the programmatic scope of AFCI, Generation IV and NHI. In 2004, the domestic NERI program has become the DOE-NE University collaboration program.

All the NPTDS Liquid Metal Cooled Reactors activities are conducted in 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 which 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.

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	United States of America
Italy	European Commission
Japan	OECD/NEA

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 co-ordinated research project 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 co-operation 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 co-ordinated research project is being conducted with the objective to reduce the calculational uncertainties of the LMFR reactivity effects. The first proposed benchmark model is based on the BN-600 hybrid core.

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 35 experimental, prototype and commercial LMFRs. Each reactor plant is characterized by about 400 parameters, by design data and by relevant graphic materials.

In response to expressed needs by Member States, NPTDS has undertaken concrete steps towards the implementation of a FR data retrieval and knowledge preservation initiative. This initiative aims at providing an overall framework for the various programs being implemented in the Member States to stop data and information being destroyed, retrieve the data, assess its importance, determine what data and information should be retained, how information from different programs could be linked, how the quality of information should be assessed, and what standards should exist in software and hardware for preservation over the next 30 – 40 years. Provided adequate funding is ensured, it would support and coordinate data retrieval activities, and establish the portal for accessing the knowledge base. By addressing issues of "institutional memory" (through, e.g., retrieval and preservation of the decision making processes, including the "false trails" followed and eventually rejected) and of passing information from one generation to the next, it aims at more than collecting information on static Web-based databases.

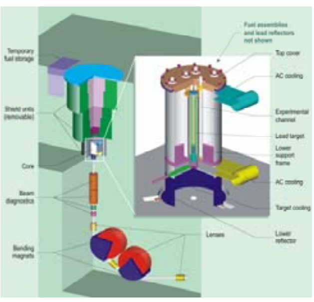
Partitioning and Transmutation

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 surmised 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 co-operation agreements. In China, the emphasis in the first phase (1998-2000) was on system optimisation, reactor physics and technology, accelerator physics and technology, and nuclear and material data. In a second phase, launched in 2000, a five-year program of basic ADS physics and related technology research is being carried out jointly by the Chinese Institute of Atomic Energy (CIAE), the Institute of High Energy Physics (IHEP), the Institute of Heavy Ion Physics of the Peking University (PKU-IHIP), and other institutions, as part of the "Major State Basic Research Program (973)", which is sponsored by the Chinese Ministry of Science and Technology (MOST). In reactor physics, a series of neutron multiplication experimental studies were carried out and are continuing. It is planned to continue the sub-critical reactor physics studies with the help of an external pulsed neutron source (Venus). Indian efforts toward exploiting the beneficial aspects of the ADS have been initiated under the framework for thorium utilization schemes of the nuclear power programme. Under this, three main R&D institutions in India have initiated ADS-related projects/planning during the five year plan (2002-2007). These are the Bhabha Atomic Research Center (BARC) at Mumbai, Variable Energy Cyclotron Centre (VECC) at Kolkata, and the Centre for Advanced Technology (CAT) at Indore. Currently ongoing activities are related to (a) experimental plan of a sub-critical core driven by 14-MeV neutrons from $T(d,n)^4He$ reaction for reactor physics studies, (b) development of a high-intensity 10-MeV proton linac as front-end of accelerator for ADS, (c) setting up molten lead-bismuth eutectic experimental loop, and (d) developing a fabrication and characterizing facility for bulk niobium superconducting RF cavities. In Japan, a 800 MW(th) sub-critical lead-bismuth eutectic cooled core concept is proposed. This ADS, using lead-bismuth eutectic for both coolant and target material, and necessitating a super-conducting LINAC with 20-

30 MW beam power, could transmute 250 kg of minor actinides per year, corresponding to the minor actinide amount produced per year in about ten 1 GW(e) LWRs. Considerable R&D work is under way and planned at JAERI in the fields of sub-critical core design, spallation target technology, accelerator development, and minor actinide fuel development. In particular, with the objective of studying and evaluating the physics and engineering feasibility aspects of the ADS, JAERI has proposed the construction of the Transmutation Experimental Facility (TEF) within the framework of the High-Intensity Proton Accelerator Project. In the Republic of Korea, KAERI has been working on the HYPER (HYbrid Power Extraction Reactor) concept since 1997. The HYPER conceptual design will be completed by 2006. KAERI's ADS R&D consists of 3 stages: a basic concept of HYPER was established in the first stage (1997 - 2000), the basic technology related to HYPER is being investigated in the second stage (2001 - 2003), and the conceptual design will be completed in the third stage (2004 - 2006). Presently, KAERI is focusing on heavy liquid metal (lead-bismuth eutectic), and on fuel studies. KAERI joined the MEGAPIE project in 2001, and has installed a static, lead-bismuth corrosion test device and started experiments. KAERI is also constructing a lead-bismuth corrosion loop, which will be completed in 2004. For the fuel studies, KAERI is discussing a possible collaboration with ANL-West, and also investigating fission product irradiation tests using its own research reactor HANARO.

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 fifth and upcoming sixth framework programme of the European Union (EU).



Conceptual Design of the Sub-critical Assembly Dubna (SA)

In Russia, there is considerable R&D effort dedicated 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 Russia include (a) the delivery of the spallation target MK-1 was to the University of Nevada, Las Vegas (UNLV), where it is currently undergoing thermohydraulic testing. This target was designed and constructed in Russia during the year 2001, for irradiation in the 800 kW proton beam of the LANL accelerator. The program for the target's start-up and duration tests under isothermal conditions was prepared; (b) analysis of a proposal to establish an international ADS demonstration project at the SSC RF IPPE site in Obninsk (Nuclear Waste Burner (NWB) project: the construction of the NWB could be completed in 7 to 8 years, and preliminary results show that a burning rate of ~10-20 kg minor actinides per year can be achieved in sub-critical core having 200 to 400 kg minor actinide inventory); and (c) the definition of RF Minatom's program of work for the sub-critical cascade molten salt reactor concept in a closed nuclear fuel cycle (RSC KI and VNIITF); and (d) activities within the framework of the ISTC Sub-critical Assembly Dubna (SAD) project (JINR).

NPTDS 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 co-ordinated research projects 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 is providing for a review and comparison of different options to achieve these aims, including review of new technical measures to achieve proliferation resistance.

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 technology development was initiated in 1997. Presently, the WWW-based version of the database is operational and data collection has started.

NUCLEAR DESALINATION

http://www.iaea.org/programmes/ne/nenp/nuclear_desalination/home_index.htm

Experience with nuclear desalination

Number of reactors	10
Number of countries with experience	3
Experience in reactor-years	~150

For human life, a sufficient amount of water and its adequate quality are essential. The scarcity of fresh-water and especially potable water is jeopardising 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 International Atomic Energy Agency (IAEA) conducts a programme on nuclear seawater desalination, i.e. the production of potable water using nuclear energy.

Members of the INDAG, Term II (2001-2004)

Argentina	Republic of Korea
Canada	Libyan Arab Jamahiriya
China	Morocco
Egypt	Pakistan
France	Saudi Arabia
India	The Russian Federation
Israel	Tunisia
Japan	United States of America

The objective of the programme in the Nuclear Power Technology Development Section (NPTD) of the IAEA is to increase the exchange of information on the introduction of nuclear desalination[6] and other non-electrical applications of nuclear energy. The main focus of the project is placed on nuclear desalination.

Since the Member States expressed their 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 the 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. INDAG continues its function for the second term from 2001.

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 150 reactor-years of successful operation. Relevant technical experience has been also accumulated in Russia, 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.

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.

In Canada a test rig has been built to obtain experimental data for verifying performance improvements of reverse osmosis (RO) membranes as operating temperature and pressure are increased. The data are expected to validate the proposed concept of "RO preheats" for seawater desalination.

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-MED process. The production capacity of the plant will be 160 000 m^3/d.

Egypt has completed its feasibility study of a nuclear co-generation plant (electricity and water) at El-Dabaa site under the IAEA technical cooperation project.

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 Frame Work Programme of European Commission.

A 6300m^3/d desalination plant is being connected to existing PHWR units at Kalpakkam, India. The desalination plant is a hybrid comprising of a reverse osmosis system and a multi-stage flash system.

India is setting up a 6300 m^3/d hybrid MSF-RO 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 2004.

6 ***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

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 Co-operation Project.

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

Pakistan is accelerating its efforts for setting up a nuclear desalination demonstration plant of up to 4800 m^3/d, to be connected to KANUPP by 2005.

In the Russian Federation the floating power unit project development is coming to the end, and construction of a pilot plant at the shipyard in Severodvinsk, Arkhangelsk Region, is planned for 2005–2006.

Tunisia is conducting 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 co-operation project.

To assess and compare different energy and technology options for desalination, the NPTD has developed a computer software package for economic assessment of nuclear and fossil options in combination with various desalination processes. An updated version of the Desalination Economic Evaluation Program, CD-ROM version, (DEEP 2.1) is available cost-free from the NPTD Section. Until January 2004, DEEP was distributed to some 250 users in over 40 Member States of which 100 License agreements have been established. Safety of nuclear desalination installations is addressed in co-operation 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 Technical Document TECDOC 1186.

To further assist Member States in 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 Report Series No. 400, 2000)

The co-ordinated 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.

A CRP on "Economic Research on, and Assessment of, Selected Nuclear Desalination Projects and Case Studies" has been 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 Agency 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 Oct. 16-18, 2002. The Agency contributed to the event by sponsoring the attendance of grantees 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". The conference has highlighted technology advances in nuclear desalination, safety, economics and financing issues as well as the issue of water needs for sustainable development. About 150 participants from 37 countries attended the event.

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

http://www.iaea.org/INPRO

The IAEA General Conference (2000) has invited "all interested Member States to combine their efforts under the aegis of the Agency 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 to contribute to a task force on innovative nuclear reactors and fuel cycle (GC(44)/RES/22). In response to this invitation, the IAEA initiated an International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO).

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, are based– to the extent possible – on systems with inherent

safety features and minimize the risk of proliferation and the impact on the environment;

- To create a process that involves all relevant stakeholders that will have an impact on, draw from, and complement the activities of existing institutions, as well as ongoing initiatives at the national and international level.

INPRO is an Agency-wide project, being co-ordinated by the Department of Nuclear Energy with contributions from all relevant Agency 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 Co-ordinating Group (ICG), comprising Cost Free Experts from INPRO Members, which co-ordinates and implements the project on the basis of experts' work in Member States and International Organizations;
- Technical Expert Groups, comprising experts from IAEA Member States, which are convened as appropriate by the ICG to consider specific subjects; and
- The Agency support, including project management, administrative and technical support.

As of September 2004, the following 21 Member States and International Organizations have become INPRO Members: Argentina, Armenia, Brazil, Bulgaria, Canada, Chile, China, Czech Republic, France, Germany, India, Indonesia, Republic of Korea, Pakistan, Russian Federation, South Africa, Spain, Switzerland, Netherlands, Turkey and the European Commission., and the membership is increasing. Members contribute to the project by providing funds, experts and studies.

To become a Member of INPRO, a Member State must either provide extra-budgetary resources in form of financial contributions or Cost-Free Experts, or perform a Work Package within the frame of INPRO scope.

In total, 25 Cost Free Experts have been nominated by INPRO Members and worked or continue to work at the Agency as members of the INPRO International Co-ordinating Group.

Before 2004 INPRO was mainly implemented by the ICG using mostly extra-budgetary resources offered by INPRO Members. Extrabudgetary contributions for 2003 and 2004 were provided by Bulgaria, Canada, Pakistan, Switzerland, Turkey, and Russian Federation. In July 2003 the IAEA Board of Governors agreed to include INPRO partly in the regular budget of the Agency, starting from 2004.

Phase-I of INPRO was initiated in May 2001. During Phase-I, work is subdivided in two sub phases:

- Phase-IA, completed in June 2003, focused on the determination of Basic Principles and User Requirements to INSs, and on the selection of Criteria and development of the Methodology and guidelines for the assessment of Innovative Nuclear Energy Systems (INSs) and their individual components.

The results of Phase-IA are presented in TECDOC 1362 "Guidance for the Evaluation of Innovative Nuclear Reactors and Fuel Cycles" issued in June 2003 as TECDOC-1362

- Phase-IB started in July 2003 and throughout 2004 is dedicated to the validation of INPRO Methodology through a series Case Studies.

In 2003-2004, case studies have been performed to validate and update the INPRO Methodology by applying it to trial assessment of specific INSs. Six INPRO Member States carried out National Case Studies for validation of INPRO Methodology:

- Argentina with CAREM-X system including CAREM reactor and SIGMA fuel enrichment process;
- India with APHWR reactor and associated U-Pu-Th fuel cycle including fast breeder reactor and accelerator-driven system for transmutation of waste;
- Republic of Korea with DUPIC fuel cycle technology;
- Russian Federation with BN sodium cooled reactor family and associated equilibrium fuel cycles;
- China with pebble-bed High Temperature Reactor.
- Czech Republic with Molten Salt Reactor.

Eight case studies for validation of the INPRO Methodology were carried out by individual experts from Russian Federation, India, France, and Argentina, they covered the technologies that were not addressed in National Case Studies, such as systems with small and medium sized reactors, systems with non-electrical applications, advanced systems with fast neutron spectrum, systems with multinational and autonomous fuel cycles, alternative energy sources, e.g. fusion, ADS and renewables, and development of tools for dynamic systems simulations as based on the INPRO methodology.

The conclusions of 6 National and 8 Individual Case Studies prove the INPRO methodology developed within INPRO Phase-IA and presented in the IAEA-TECDOC-1362 to be useful for the assessment of INSs targeted for deployment within the first half of the 21st century.

In the second part of Phase 1B, to be started in 2005, INPRO expects its validated and upgraded methodology to be applied by several interested Member States, who are invited to look into the capabilities and potentials of the existing or proposed INSs. The necessary data for these assessments will be provided to the extent possible via the Agency within the INPRO project. Furthermore, INPRO is offering any assistance needed to participating Member States in the performance of such an assessment. The outcome of these studies should be a basis for the decision on how to proceed with the development and/or deployment of a nuclear energy system in these Member States.

TECDOC on "Innovative Fuel Cycle Technologies: Status and Trends" is under preparation within the framework of INPRO. This TECDOC will summarize the status of innovative nuclear fuel cycles and associated nuclear reactor developments and will provide information for Member States on innovative nuclear energy systems (INSs) for their assessment within the second part of INPRO Phase-IB. The TECDOC will be submitted for publication by the end of 2004.

Upon successful completion of Phase-I, taking into account advise from the INPRO Steering Committee, and with the approval of participating Member States, Phase-II of INPRO may be initiated. Drawing on the results from Phase-I, it will be directed to:

- Examining in the context of available technologies the feasibility of commencing an international collaborative project;
- Identifying innovative technologies, which might be appropriate for implementation by Member States of such an International Project.

Phase-II of INPRO is still in the planning stage. Any decisions on its final content and direction will be made by INPRO members and will require approval by the INPRO Steering Committee.

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 is very long, and covers the next five decades. Energy scenarios for the period envisaged are determined by an expected transformation of the energy sector in the 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 have to 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.

INPRO already participates as an observer in the meetings of the Generation-IV International Forum (GIF) Policy and Expert Groups. Further cooperation is being discussed.

IAEA/INPRO pursues increased cooperation with other international efforts targeted at innovative technology development, such as Generation-IV International Forum (GIF). On 22-26 March 2004, a meeting on proliferation resistance of innovative nuclear energy systems was convened in Cheju, Republic of Korea, with participation of experts from the Agency Secretariat, INPRO, and GIF.

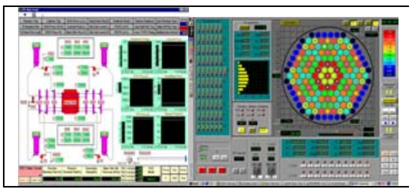
USER FRIENDLY EDUCATION WITH NUCLEAR REACTOR SIMULATORS

http://www.iaea.org/OurWork/ST/NE/NENP/NPTDS/Projects/edu.html

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 services based on the use of nuclear reactor simulators.

To assist Member States in nuclear education, the Agency sponsors the development of nuclear reactor simulators which operate on personal computers and which simulate responses of a number of reactor types to operating and accident conditions.

The simulators provide teaching tools for university professors and engineers involved in teaching topics in nuclear energy and are also supplied directly to students, junior engineers, and senior engineers and scientists interested in broadening their understanding of the topic.



Computer screens from the simulators

The Agency arranges for the supply or development of such simulation programs and teaching material, sponsors workshops, and distributes documentation and computer programs.

Since 1997, twelve workshops have been held, in Egypt, Saudi Arabia, the Republic of Korea, Italy, Vienna and the United States. Training has been given, and reactor simulators have been distributed to more than 238 participants from 46 countries, for educational purposes. The workshops are now an annual activity sponsored by the International Centre for Theoretical Physics, Trieste, Italy and the IAEA.

Several simulation programs are available for distribution covering different type of reactors namely a CANDU; a BWR; a conventional PWR; a PWR with passive safety systems; and a WWER-1000.

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

SUPPORT TO TECHNICAL CO-OPERATION ACTIVITIES

Recently, most of the support to Technical Co-operation activities has addressed nuclear desalination. 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 co-operative activities in this field. An interregional project has been launched in 1999 to provide a forum for exchanging information on potential demonstration projects of nuclear desalination by interested Member States. Also assistance is being provided to Egypt for its feasibility study on a nuclear desalination project at El-Dabar 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 Technical Co-operation Project on “Integrated Nuclear Power and Desalination System Design” was launched in 1999. The project is being planned to encompass international collaboration between technologies 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 joint study on “Preliminary economic feasibility of nuclear desalination in Madura Island, Indonesia” was signed between Indonesia and the Republic of Korea and the 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 draft report is ready for review.Pakistan has completed the basic design study of a 4800 cubic meter per day desalination plant to be established at KANUPP, Karachi. .

A new International Technical Cooperation Project (INT/4/141) “Innovative Nuclear Reactors and Fuel Cycles” was launched in the beginning of 2003. In its frame innovative reactor and fuel cycle concepts and how they would meet user requirements in terms of design, safety, economics and proliferation resistance will be examined. A workshop on “Safety demonstration and market potential of High Temperature Gas Cooled Reactors (HTGR)” is planned at the INET institute in Beijing, China in April 2004. A second workshop on “Progress in Design of Innovative Reactor Concepts” is also planned to be convened in the Republic of Korea during 2004.

Also a Technical Cooperation Programme for Argentina “Evaluation of the Technological Potential of Advanced Nuclear Power Plants” (ARG/04/086) was launched in the beginning of 2003. The objectives are to determine the potential of new technologies in the design of nuclear reactors as an option to meet future regional energy requirements in Argentina. It is expected that the results will show the potential alternatives for technological developments for new NPPs for Argentina and the region, based on a significant reduction of electricity costs, future demand of electricity, and sustainable technological capabilities in the region.

Active Co-ordinated Research Projects as of January 2004

International co-operative research programmes are established by the IAEA in areas that are of common interest to a number of Member States. These co-operative efforts are carried out through Co-ordinated 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, foster team-building and benefit from the experience and expertise of researchers from all participating institutes.

Intercomparison of techniques for pressure tube inspection and diagnostics

Argentina, Canada, China, India, Republic of Korea and Romania.

The project is to intercompare inspection and diagnosis techniques for characterization of pressure tubes during their service lifetimes as being used, and developed, by different participating institutions.

Natural Circulation Phenomena, Modelling and Reliability of Passive Systems that Utilize Natural Circulation

Argentina, Czech Republic, France, Germany, India, Italy, Japan, Rep. of Korea, the Netherlands, Spain, Switzerland, Slovakia, the Russian Federation, and the United States of America

The application of passive safety systems is a potential means of achieving simplification and competitive economics in new nuclear power plant designs. The use of passive systems is not entirely new, and is not unique to any particular line of new reactor designs. But an increased reliance on this approach, making safety functions less dependent on active components like pumps and diesel generators, is potentially an important means to achieve reduced costs for future nuclear power plants. Many new reactor designs incorporate passive systems based on natural circulation.

The objectives of this CRP are (1) To establish the state of the art in the area of natural circulation including the consideration of reactor start-up and operation, passive system initiation and operation, flow stability, 3-D effects and scaling laws; (2) to identify and investigate phenomena (e.g. effect of non-condensable gases on heat transfer, thermal stratification, mass stratification, pool heat transfer, moisture carryover, and others) influencing the reliability of passive systems that utilize natural circulation; (3) to identify relevant experimental databases for these phenomena, review for completeness, recommend further work as needed, and collect openly available experimental data (4) to examine the ability of current computer codes and models to predict natural circulation and related phenomena that affect the system reliability through sharing assessments, experience, performing standard problem exercises and identifying ways of making improvements, etc. To determine the associated uncertainties, and to perform sensitivity analyses on the importance of various phenomena; and (5) to develop and apply methodologies for determining the reliability of passive systems that utilize natural circulation and to introduce this into sample accident sequence analyses.

Optimization of the Coupling of Nuclear Reactors and Desalination Systems

Argentina, Canada, China, Egypt, India, Indonesia, Republic of Korea, The Russian Federation, Tunisia

This CRP encompasses research and development programmes in interested Member States pursuing coupling of nuclear systems with seawater desalination process in the field of nuclear reactor design, optimization of thermal coupling, performance improvement of desalination systems and prospects of advanced desalination technologies for the application of nuclear desalination.

Evaluation of high temperature gas cooled reactor performance

China, France, Germany, Indonesia, Japan, The Netherlands, The Russian Federation, South Africa, Turkey, The United States of America

This CRP involves the simulation of reactor physics and thermal hydraulic benchmark experiments being conducted by the HTTR and HTR-10 experimental reactors in Japan and China, as well as critical experiments on a mock-up of the PBMR core in the ASTRA critical facility in Russia and analytical comparison of reactor physics problems for the GT-MHR with a plutonium core. 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, The Russian Federation, United Kingdom, United States of America

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, The Netherlands, Republic of Korea, The Russian Federation, United States of America

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, Russia, 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 programs.

Economic Research on, and Assessment of, Selected Nuclear Desalination Projects and Case Studies

Argentina, Canada, China, Egypt, France, India, Rep. of Korea, Pakistan, the Russian Federation, Syria, 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.

Technical Documents Published by NPTDS 1995-2004

2004

Series and No.	Title, Summary
TECDOC-1406	**Primary Coolant Pipe Rupture Event in Liquid Metal Cooled Reactors** *The TECDOC reviews the safety philosophy for the primary coolant pipe (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 analyses of the event per se for flows and/or temperatures and improved design concepts for minimizing the consequences to the core.*
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 of the 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.*
TECDOC-1391	**Status of Advanced LWR Designs: 2004** *This document presents an overview of development trends and goals, and presents detailed descriptions of 35 advanced LWR designs according to a common outline. The descriptions include summaries of measures taken by the designers to enhance economy and maintainability.*

2003

Series and No.	Title, Summary
TECDOC-1382	**Evaluation of the High-Temperature Gas Cooled Reactor Performance: Benchmark Analysis Related to Initial Testing of HTTR and HTR-10** *The TECDOC documents a first set of high-temperature gas-cooled reactor core physics and thermal-hydraulic benchmarks, comparing code-to-code and code-to-experiement results. Experimental data is based on critical tests related to the startup of the HTTR and HTR-10 test reactors.*
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.*
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
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.*
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.*
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.*
TCS 23	**Boiling Water Reactor Simulator: Workshop Material** *Workshop material presenting the Boiling Water Reactor (BWR) Simulator developed for the IAEA by Cassiopeia Technologies Inc. of Canada*
TCS 22	**Pressurized Water Reactor Simulator: Workshop Material** *Workshop material presenting the Pressurized Water Reactor (PWR) Simulator developed for the IAEA by Cassiopeia Technologies Inc. of Canada*

2002

Series and No.	Title, Summary
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.*
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.*
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.*

Series and No.	Title, Summary
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 Agency, including expertise in the Nuclear Power Engineering Section and the Planning and Economic Studies Section of the Department of Nuclear Energy, and in the Division of Nuclear Installation Safety of the Department of Nuclear Safety.*
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.*
TECDOC-1288	**Verification of Analysis Methods for Predicting the Behavior 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)*
TECDOC-1281	**Natural Circulation Data and Methods for Advanced Water Cooled Nuclear Power Plant Designs** *Proceedings of a 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*
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*
C&S Paper Series 14/P	**Small and Medium Sized Reactors: Status and Prospects** *Proceedings of an International Seminar held in Cairo, Egypt in May 2001 organized by the IAEA in co-operation with the OECD Nuclear Energy Agency and the World Nuclear Association*
AEN/NEA and IAEA 2002 Publication	**Innovative Nuclear Reactor Development, - Opportunities for International Co-operation** *This report has been authored and produced by the "Three-Agency Study", a joint project of the IEA, the NEA and the IAEA. The conclusions and recommendations contained in the report are the work of all three agencies.*

Series and No.	Title, Summary
TRS-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 applications. A less detailed assessment of some innovative applications (e.g. hydrogen production and coal gasification) is also provided.*
TCS 21	**WWER-1000 Reactor Simulator: Workshop Material** *Workshop material presenting the WWER-1000 Reactor Department Simulator from the Moscow Engineering and Physics Institute, Russia*

2001

Series and No.	Title, Summary
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*
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 behavior 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 behavior, 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, the Netherlands, the 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 fueled 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 programs in the Russian Federation and Japan was also utilized.*
TECDOC-1239	**Critical Experiments and Reactor Physics Calculations for Low-Enriched HTGRs** *This report documents the results of an IAEA CRP 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.*
TCS 12	**Workshop material presenting techniques and tools for reactor simulator development** *Training Course Series 12, 'Reactor Simulator Development', IAEA, Vienna 2001.*
TECDOC-1238	**Gas turbine power conversion systems for modular HTGRs** *The information presented in this report was developed from an IAEA TCM on "Gas Turbine Power Conversion Systems for Modular HTGRs", held in 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.*

Series and No.	Title, Summary
TECDOC-1236	**Design and evaluation of heat utilization systems for the High Temperature Engineering Test Reactor** *This report documents the results of an IAEA CRP 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.*
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.*
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.*
TECDOC-1203	**Thermohydraulic Relationships for Advanced Water Cooled Reactors** *This report has been prepared within the IAEA's CRP on "Thermohydraulic Relationships for Advanced Water Cooled Reactors" which was started in 1995 with the overall goal to promote information exchange and co-operation 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.*
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.*
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
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 Programme (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 Agency requests all users to establish a license agreement for DEEP.*

Series and No.	Title, Summary
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.*
TECDOC-1180	**Unusual Occurrences During LMFR Operation** *Proceedings of a TCM held in Vienna, 9-13 November 1998.*
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.*
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, July 1998.*
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.*
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.*
TECDOC-1157	**LMFR Core Thermohydraulics: Status and Prospects** *Review of data, codes and methodologies for LMFR core thermohydraulic calculations.*
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.*
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.*
TECDOC-1149	**Experimental tests and qualification of analytical methods to address thermohydraulic phenomena in advanced water-cooled reactors** *Proceedings of a TCM hosted by Paul Scherer Institute in Switzerland in September 1998 convened to review the current status and the future needs in this area.*
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.*

Series and No.	Title, Summary
TECDOC-1054	**Technologies for improving the availability and reliability of current and future water cooled nuclear power plants** *Proceedings of a TCM held in Argonne, Illinois, United States of America, 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.*

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Series and No.	Title, Summary
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.*
TECDOC-1117	**Evolutionary Water Cooled Reactors: Strategic Issues, Technologies and Economic Viability** *Proceedings of a Symposium hosted by KEPCO in December 1998*
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.*
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.*
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*
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.*

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Series and No.	Title, Summary
TECDOC-1043	**Technologies for gas cooled reactor decommissioning, fuel storage and waste disposal.** *Proceedings of a Technical Committee meeting held in Julich, Germany, Sept. 1997.*
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 June 1997.*
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.*
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.*
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.*
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 Report Series-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.*
TC-903.3	**Feasibility and motivation for hybrid concepts for nuclear energy generation and transmutation** *Proceedings of the IAEA Technical Committee Meeting*

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Series and No.	Title, Summary
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.*
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 fueling machines and fuel options.*
TECDOC-917	**Potential for Nuclear Desalination as a Possible Source of Low Cost Potable Water in North Africa, (Arabic Version)**
TECDOC-898	**Options Identification Programme for Demonstration of Nuclear Desalination, (Arabic Version).**

Series and No.	Title, Summary
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.*
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.*
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.*
TECDOC-965	**Design approaches for heating reactors** *Progress in the development of reactors for supplying low temperature heat, currently of interest for seawater desalination.*
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.*
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.*
TECDOC-948	**Status report on actinide and fission product transmutation studies** *An up-to-date general overview of current and planned research on transmutation.*
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).*
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.*
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.*
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.*
TECDOC-933	**Creep-fatigue damage rules for advanced fast reactor design** *Proceedings of a TCM held in Manchester, United Kingdom, 11-13 June 1996.*

Series and No.	Title, Summary
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

Series and No.	Title, Summary
TECDOC-920	**Technical feasibility and reliability of passive safety systems for nuclear power plants** *Proceedings of an AGM held in Julich, Germany, 21-24 November 1994.*
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.*
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.*
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.*
TECDOC-907	**Conceptual design of advanced fast reactors** *Proceedings of a TCM held in Kalpakkam, India, 3-6 October 1995.*
TECDOC-901	**Graphite moderator lifecycle behaviour** *Proceedings from the Specialists Meeting held in 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.*
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.*
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.*
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.*
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.*

Series and No.	Title, Summary
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.*
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.*
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.*
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.*
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.*
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.*
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.*

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Series and No.	Title, Summary
TECDOC-849	**In-core fuel management code package validation for BWRs** **(see TECDOC 815)**
TECDOC-847	**In-core fuel management code package validation for WWERs** **(see TECDOC 815)**
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.*
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.*
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.*

Series and No.	Title, Summary
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.*
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 TECDOCs 847, 849).*
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.*
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.*
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.*