Nuclear Power

Objective

To enhance the capability of interested Member States, in a rapidly changing market environment, to improve nuclear power plant operating performance, life cycle management including decommissioning, human performance, quality assurance and technical infrastructure, through good practices and innovative approaches consistent with global objectives on non-proliferation, nuclear safety and security. To enhance the capacity of Member States for the development of evolutionary and innovative nuclear system technology for electricity generation, actinide utilization and transmutation and for non-electric applications, consistent with sustainability goals. To facilitate the improvement of public understanding of nuclear power.

Launching Nuclear Power Programmes

More than 60 countries — mostly in the developing world — have informed the Agency that they might be interested in launching nuclear power programmes. In 2009, 58 Member States participated in regional or national technical cooperation projects related to the introduction of nuclear power. Of these States, 17 were actively preparing national nuclear power programmes. Iran was constructing its first nuclear power plant, and the United Arab Emirates completed a bidding process for its first nuclear power plant. In December, it selected the bid by a consortium led by the Korea Electric Power Corporation and the Emirates Nuclear Energy Corporation. The increased interest among Member States led to a threefold increase in technical cooperation projects related to nuclear power in the Agency's 2009–2011 technical cooperation cycle. Agency assistance to countries launching nuclear power programmes includes: technical guidance and reference documents; the dissemination of experience, new knowledge and best practices; direct training and computer packages for distance learning; and peer reviews and other expert advisory missions.

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In 2009, the Agency launched a new Integrated Nuclear Infrastructure Review (INIR) service to examine national infrastructure needs based on the 'milestones' it has developed to guide Member States as they embark on a nuclear power programme.[1] The first three INIR missions visited Jordan, Indonesia and Vietnam. Opportunities for international cooperation between newcomer countries and the vendor community were identified in an Agency workshop in November, and new publications were issued on financing nuclear power plants and on the responsibilities and capabilities of owners and operators, and of organizations, in implementing new nuclear power programmes.

Engineering Support for Operation, Maintenance and Plant Life Management

The Agency's support for Member States with operating nuclear power plants continues to focus on operational excellence, especially by extending the operational life of such plants through the replacement of heavy components. Many Member States give high priority to long term operation of reactors beyond the 30–40 years originally anticipated. Out of a total of 437 nuclear power reactors in operation at the end of 2009, 339 had been in operation for more than 20 years.

Two CRPs related to the integrity of reactor pressure vessels were completed in 2009 and their final reports published: *Pressurized Thermal Shock in Nuclear Power Plants: Good Practices for Assessment* (IAEA-TECDOC-1627) and *Master Curve Approach to Monitor Fracture Toughness of Reactor Pressure Vessels in Nuclear Power Plants* (IAEA-TECDOC-1631). The first CRP concluded that under certain well specified conditions, different national codes for assessing pressurized thermal shock produced consistent results. The factors that most influenced the assessment results were the size, shape, location and orientation of flaws in the material, thermohydraulic assumptions and material toughness. Less influential factors were the vessel steel stress-strain curve, fatigue crack growth, and the profile of weld

[1] *Milestones in the Development of a National Infrastructure for Nuclear Power*, IAEA Nuclear Energy Series No. NG-G-3.1, IAEA, Vienna (2007).

FIG. 1. Construction of water cooled reactors (2 × 917 MW(e)) at Kundankulam, in India.

residual stresses. The second CRP confirmed the applicability of the master curve approach under most conditions, identified exceptional conditions and recommended adjustments, and identified biases in toughness tests related to the size and geometry of the specimens tested. The Agency also published *Integrity of Reactor Pressure Vessels in Nuclear Power Plants: Assessment of Irradiation Embrittlement Effects in Reactor Pressure Vessel Steels* (IAEA Nuclear Energy Series NP-T-3.11).

Nearly all power reactors in operation and under construction are water cooled reactors (Fig. 1), and in October the Agency convened a conference on 'Opportunities and Challenges for Water Cooled Reactors in the 21st Century'. The conference attracted 270 participants from 54 Member States, nearly twice the number of countries with operating nuclear power plants. The conference participants discussed projections for the continued expanding demand for water cooled reactors and the central role they will play in the 21st century. It provided an opportunity for participants to share lessons learned from operational and regulatory experience so as to improve the design, operation and safety of the expanding fleet of water cooled reactors. The participants also discussed prospects for innovative applications of water cooled reactors. The conference identified the need for additional efforts to develop advanced materials and reliable components for longer plant lifetimes and more demanding conditions, to clarify the optimal balance between active and passive safety systems, to make more effective use of alternative fuels and advanced fuel designs, and to attain higher conversion rates.

The Agency established a new review mission — Independent Engineering Review of I&C Systems (IERICS) — to peer review design documents, prototype systems, and I&C systems already deployed in operating nuclear power plants. The first three IERICS missions will take place in 2010.

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The Agency also established a new international network of instrumentation and control (I&C) experts, the Network of Excellence for Supporting the Use of I&C Technologies for the Safe and Effective Operation of Nuclear Power Plants (NE-ICT). In related work, the Agency completed two publications in the area of I&C modernization: *Implementing Digital Instrumentation and Control Systems in the Modernization of Nuclear Power Plants* (IAEA Nuclear Energy Series No. NP-T-1.4) and *Protecting against Common Cause Failures in Digital I&C Systems of Nuclear Power Plants* (IAEA Nuclear Energy Series No. NP-T-1.5).

TABLE 1. NUCLEAR POWER REACTORS IN OPERATION AND UNDER CONSTRUCTION IN THE WORLD (AS OF 1 JANUARY 2010)[a]

Country	Reactors in operation		Reactors under construction		Nuclear electricity supplied in 2008		Total operating experience through 2009	
	No. of units	Total MW(e)	No. of units	Total MW(e)	TW·h	% of total	Years	Months
Argentina	2	935	1	692	6.9	6.2	62	7
Armenia	1	376			2.3	39.4	35	8
Belgium	7	5 863			43.4	53.8	233	7
Brazil	2	1 766			13.2	3.1	37	3
Bulgaria	2	1 906	2	1 906	14.7	32.9	147	3
Canada	18	12 577			88.3	14.8	582	2
China	11	8 438	20	19 920	65.3	2.2	99	3
Czech Republic	6	3 678			25.0	32.5	110	10
Finland	4	2 696	1	1 600	22.1	29.7	123	4
France	59	63 260	1	1 600	419.8	76.2	1 700	2
Germany	17	20 470			140.9	28.8	751	5
Hungary	4	1 859			13.9	37.2	98	2
India	18	3 984	5	2 708	13.2	2.0	318	4
Iran, Islamic Republic of			1	915				
Japan	54	46 823	1	1 325	241.3	24.9	1 439	5
Korea, Republic of	20	17 647	6	6 520	144.3	35.6	339	8
Mexico	2	1 300			9.4	4.0	35	11
Netherlands	1	482			3.9	3.8	65	0
Pakistan	2	425	1	300	1.7	1.9	47	10
Romania	2	1 300			10.3	17.5	15	11
Russian Federation	31	21 743	9	6 894	152.1	16.9	994	4
Slovakia	4	1 711	2	810	15.5	56.4	132	7
Slovenia	1	666			6.0	41.7	28	3
South Africa	2	1 800			12.8	5.3	50	3
Spain	8	7 450			56.5	18.3	269	6
Sweden	10	8 958			61.3	42.0	372	6
Switzerland	5	3 238			26.3	39.2	173	10
Ukraine	15	13 107	2	1 900	84.5	47.4	368	6
United Kingdom	19	10 097			48.2	13.5	1 457	8
United States of America	104	100 683	1	1 165	806.7	19.7	3 499	9
Total[b, c]	437	370 187	55	50 855	2 597.8	14	13 911	3

[a] Data are from the Power Reactor Information System.

[b] The total includes the following data on Taiwan, China:

— 6 units, 4949 MW(e) in operation; 2 units, 2600 MW(e) under construction.

— 39.3 TW·h of nuclear electricity generation, representing 17.5% of the total electricity generated there.

— Total operating experience at the end of 2009: 170 years, 1 month.

[c] The total operating experience also includes shutdown plants in Italy (81 years), Kazakhstan (25 years, 10 months) and Lithuania (43 years, 6 months).

In addition to publications, the Agency also disseminates information on nuclear power reactors through its web site. For reactor operations, a key information source is the Power Reactor Information System (*http://www.iaea.org/pris*), which is kept up to date by national contributors from all countries with reactors that are under construction, in operation or shut down (Table 1).

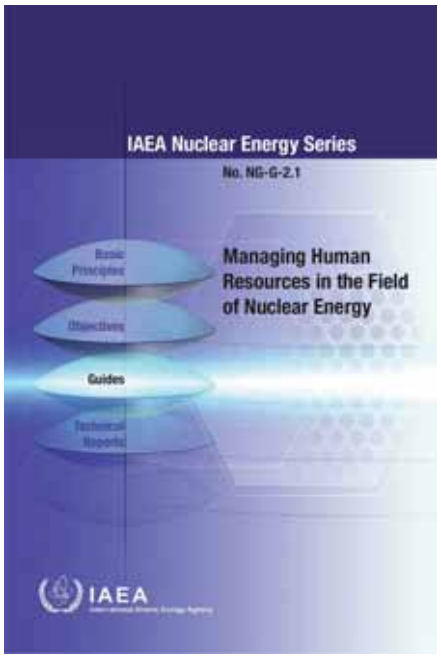

FIG. 2. The Agency published a new guide on the essential steps in managing the supply of a competent workforce for nuclear power programmes.

Human Resource Management

With increased interest in nuclear power, concerns have been expressed about possible shortages of individuals with the necessary skills. The Agency helps to analyse trends and needs, facilitates information sharing, provides training, and publishes technical guidance and reference material (Fig. 2). In 2009, the Agency organized, with support from the US Department of Energy, an interregional training course on leadership and management of nuclear power programmes in countries introducing nuclear power. It also held regional workshops in Latin America and Europe on human resources for new nuclear power programmes, and national workshops in Belarus, Chile, Egypt, Ghana, Thailand and Vietnam. It provided assistance on staff training at nuclear power plants under continuing technical cooperation projects, and convened a meeting in Vienna on simulators, advanced training tools and technologies for the nuclear industry, with a special session on the development of training systems for countries introducing nuclear power. It also published a new guide, *Managing Human Resources in the Field of Nuclear Energy* (IAEA Nuclear Energy Series No. NG-G-2.1).

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Nuclear Reactor Technology Development

The Agency seeks to stimulate innovation in nuclear power through activities in four areas:

- Light water, heavy water, gas cooled and fast reactors;
- Small and medium sized reactors (SMRs);
- Non-electric applications, such as hydrogen generation and desalination using nuclear power;
- The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO).

In addition to the international conference mentioned on page 20, the Agency organized a number of meetings, workshops and courses dealing with water cooled reactors. For example, a technical meeting on improved pellets and advanced fuel designs reviewed the status of developments in fuel pellet materials as well as recent improvements in fuel rod designs for advanced cooled power reactors. A two week workshop on 'PC Based Simulators for Education' was held at the ICTP in Trieste, Italy, to demonstrate the Agency's simulators and advise participants on their best use as a training and educational tool. In June, the University of Pisa hosted an Agency course on Natural Circulation in Nuclear Power Plants.

The Agency published *Passive Safety Systems and Natural Circulation in Water Cooled Nuclear Power Plants* (IAEA-TECDOC-1624), which provides insights into system design, operation and reliability. The report was the result of a CRP on natural circulation phenomena, modelling and reliability of passive systems that brought together 16 institutes from 13 Member States. The Agency also published *Intercomparison of Techniques for Inspection and Diagnostics of Heavy Water Reactor Pressure Tubes: Determination of Hydrogen Concentration and Blister Characterization* (IAEA-TECDOC-1609), which presents the most effective HWR pressure tube inspection and diagnostic methods, and identifies further development needs.

In the area of gas cooled reactors, the Agency started a new CRP on Improved Understanding of the Creep Phenomenon for Irradiated Nuclear Graphite. The objective is to develop a universally accepted graphite creep model, based on experimental data, to address both regulatory

issues on life extensions for advanced gas cooled reactors in the United Kingdom and graphite qualification issues for the new high temperature gas cooled reactor (HTGR) programmes in China, South Africa and the USA. To identify available data and knowledge gaps related to these new HTGR programmes, the Agency organized a technical meeting, hosted by the Jülich Research Centre in Germany, on the performance of past HTGR programmes and test facilities. This meeting identified extensive data on the performance of past HTGRs.

In the area of fast reactors, the Agency organized an international conference in Kyoto on 'Fast Reactors and Related Fuel Cycles: Challenges and Opportunities', hosted by the Japan Atomic Energy Agency. In addition to the scientific presentations, a 'Young Generation Event' was held, underlining the fact that technology development for fast reactors and associated fuel cycles is once again receiving attention in research, and industrial and academic organizations. The participants identified a number of issues, and plans for R&D programmes to resolve them were outlined. The current focus is on the commissioning of experimental fast reactors, including the Chinese experimental fast reactor in 2010, the restart of the Monju industrial prototype in Japan in 2010, the completion of the 500 MW(e) prototype fast breeder reactor in India and the 800 MW(e) BN-800 in the Russian Federation, as well as other construction projects in France, India, Japan, the Republic of Korea and the Russian Federation.

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The Agency also organized a topical meeting, in cooperation with the American Nuclear Society, on accelerator applications, including nuclear materials research, accelerator technology and accelerator driven systems (ADSs) utilizing and transmuting minor actinides and long lived fission products. Participants agreed that ADSs have the potential to reduce the amount and toxicity of high level nuclear waste generated by power production and that the Agency should both play a significant role in progress towards an ADS demonstration plant and continue to coordinate research on ADS related nuclear data, cross-section measurements, codes and data validation, materials development and coolant technology.

Publications completed in 2009 on fast reactors included: *Advanced Reactor Technology Options for Utilization and Transmutation of Actinides in Spent Nuclear Fuel* (IAEA-TECDOC-1626); *Decommissioning of Fast Reactors after Sodium Draining* (IAEA-TECDOC-1633); and *BN-600 Hybrid Core Benchmark Analyses* (IAEA-TECDOC-1623). The last publication reports the results of a CRP on updated codes and methods to reduce the calculational uncertainties of liquid metal fast reactor reactivity effects.

In the area of small and medium sized reactors, the Agency published *Design Features to Achieve Defence in Depth in Small and Medium Sized Reactors* (IAEA Nuclear Energy Series No. NP-T-2.2).

Non-electric applications of nuclear power continue to be an area of strong interest to Member States. In response, the Agency organized a technical meeting hosted by the Korea Atomic Energy Research Institute, in Daejeon, the Republic of Korea, which emphasized the importance of international collaboration given the high R&D costs for non-electric applications, notably for nuclear hydrogen production. The meeting recommended that existing nuclear facilities related to non-electric applications should be made available for international cooperation and that more attention be given to coupling and safety issues associated with non-electric applications. It encouraged the Agency to develop new standards on these issues. The Agency also organized a workshop on the technology and performance of desalination systems, which trained participants in carrying out technology and performance evaluations of energy sources and water desalination systems, including those coupling various sources of energy, such as combined cycles, gas turbines, fossil and nuclear reactors, with different desalination processes. The course also trained participants in the use of the Agency's Desalination Economic Evaluation Program (DEEP).

The Agency began a CRP on new technologies for seawater desalination using nuclear energy. The CRP will investigate the potential to harness waste heat in nuclear power plants using heat pipe technologies.

Environmental Impact Assessment of Nuclear Desalination (IAEA-TECDOC-1642) was completed in 2009. It provides an overview of the nature and magnitude of the environmental impacts of nuclear desalination, detailing experimental data and the experience gained in operating nuclear desalination projects, and highlighting risks perceived by the public.

The Agency released a 'toolkit' on nuclear desalination. The toolkit, intended for Member

States considering nuclear power for seawater desalination, provides access to information on DEEP, Agency publications on nuclear desalination, Agency activities in the field, the work of the Technical Working Group on Nuclear Desalination, options for seawater desalination and launching a nuclear desalination programme.

Another computer code, the Hydrogen Economic Evaluation Program (HEEP), was released to evaluate the economic aspects of hydrogen production using nuclear energy. An Agency technical meeting, hosted by the Bhabha Atomic Research Centre in India, concluded that hydrogen will be an important commodity for Member States, and the hydrogen generated using nuclear energy offers much lower greenhouse gas emissions than that generated from fossil fuels.

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INPRO provides a forum for technology holders and users to jointly consider innovation. Since its establishment in 2001, INPRO has grown to 31 members, representing 75% of the world's GDP and 65% of the world's population. Since 2001, 38 cost free experts from 16 Member States have contributed to INPRO's work. In 2009, INPRO's activities were consolidated into five new substantive areas: nuclear energy system assessments (NESAs) using the INPRO methodology; global vision, scenarios and pathways to sustainable nuclear development; innovations in nuclear technology; innovations in institutional arrangements; and the INPRO dialogue forum on nuclear energy innovations.

New guidance was made available to Member States in *Lessons Learned from Nuclear Energy System Assessments (NESA) Using the INPRO Methodology* (IAEA-TECDOC-1636) and a brochure on *IAEA Tools and Methodologies for Energy System Planning and Nuclear Energy System Assessments*. The latter describes an integrated way of using Agency tools in support of both *energy* and *nuclear energy* planning. In 2009, Belarus started a new NESA for the first two nuclear power plants to be built by 2016 and 2018 and the associated waste management issues.

An Agency study, within the framework of INPRO, on *Global Scenarios and Regional Trends of Nuclear Energy Development in the 21st Century* was concluded in 2009. It analyses the perspective for long term sustainable nuclear energy development based on scientific and technical calculations of possible growth scenarios. The study also details the links between industrial capacity, resources, and flows of nuclear fuel and other nuclear material between regions.

Sustainable expansion of nuclear power will require both technical and institutional innovations. In 2009, the Agency published *Status and Trends of Nuclear Technologies* (IAEA-TECDOC-1622), which provides an overview of the history, present situation and future perspectives of nuclear fuel cycle technologies. Also in 2009, a key study on *Legal and Institutional Issues of Transportable Nuclear Power Plants* was concluded. Such power plants are of particular interest for areas with limited infrastructure, countries with small electric grids, and remote or isolated islands.