

Nuclear Power

Objective

To support Member States with existing nuclear power plants to enhance performance and ensure safe, secure, efficient and reliable long term operation, including development of human resource capability, leadership and management systems. To assist Member States embarking on new nuclear power programmes in planning and building their national nuclear infrastructures, including development of human resource capability, leadership and management systems. To provide methods and tools to support modelling, analyses and assessments of future NESs for sustainable development of nuclear energy, and collaborative frameworks and support for technology development and deployment of advanced nuclear reactors and non-electric applications.

Launching Nuclear Power Programmes

The Agency continued to support Member States considering or embarking on a new nuclear power programme by providing assistance through national workshops, expert missions, regional and interregional training activities, and review services. In 2018, 28 Member States were actively considering, planning or embarking on a nuclear power programme, four of which were constructing their first nuclear power plant (Table 1).

TABLE 1. Number of Member States considering or embarking on a nuclear power programme, according to their official statements (as of 31 December 2018)

First nuclear power plant started construction/under construction	4
First nuclear power plant ordered, but construction not yet started	1
Decided to introduce nuclear power and started preparing the appropriate infrastructure	4
Active preparation for a possible nuclear power programme with no final decision	8
Considering nuclear power programme	11

The Integrated Nuclear Infrastructure Review (INIR) continued to be one of the main Agency review services for countries embarking on a nuclear power programme, assisting them in evaluating the status of their nuclear power infrastructure development and in identifying gaps. In 2018, the Agency conducted INIR Phase 1 missions to the Niger, the Philippines and the Sudan, and an INIR Phase 2 mission to Saudi Arabia. The first INIR Phase 3 mission was conducted to the United Arab Emirates. A total of 27 INIR and INIR follow-up missions have been deployed to 20 Member States since the launch of this service in 2009 (Table 2).

TABLE 2. INIR missions conducted to Member States as of 31 December 2018

Region	Embarking	Expanding
Africa	Ghana, Kenya, Morocco, Niger, Nigeria, Sudan	South Africa
Asia and the Pacific	Bangladesh, Indonesia, Jordan, Malaysia, Philippines, Saudi Arabia, Thailand, United Arab Emirates, Viet Nam	
Europe	Belarus, Kazakhstan, Poland, Turkey	

The Agency, through its technical cooperation programme, continued to support Member States in understanding nuclear infrastructure issues using the Milestones approach. The key areas of focus in 2018 were leadership and management systems, workforce planning and human resource development, stakeholder involvement and public communication, radioactive waste management, resource requirements, and financial risks associated with nuclear power infrastructure development. Through interregional, regional and national workshops, training courses and fellowships, the Agency provided practical training in various infrastructure issues to over 400 participants, including members of nuclear power development projects, regulatory bodies and technical support organizations.

The Agency held its annual Technical Meeting on Topical Issues in the Development of Nuclear Power Infrastructure in Vienna from 30 January to 2 February. At the meeting, 64 participants from 28 Member States and an international organization discussed challenges and exchanged experiences on a range of issues, including stakeholder involvement, the structure of owner/operator organizations, and infrastructure development for small and medium sized or modular reactors (SMRs). At a Technical Meeting on the Responsibilities and Capabilities of Owners and Operating Organizations in New Nuclear Power Programmes held in Vienna in July, 16 participants from 6 countries considering or embarking on a nuclear power programme and 7 countries operating nuclear power plants discussed the draft revision of *Initiating Nuclear Power Programmes: Responsibilities and Capabilities of Owners and Operators* (IAEA Nuclear Energy Series No. NG-T-3.1). The revised publication will further elaborate new issues and strategies for establishing an owner/operator organization and developing its competence.

The Technical Meeting on Funding for Waste Management and Decommissioning, also held in Vienna in July, focused on prospective capital and operating expenditures associated with the back end of the nuclear fuel cycle, other operational waste and the waste emerging from decommissioning of nuclear power plants and other nuclear facilities. The meeting was attended by 32 participants from 23 Member States — both embarking countries and countries with operating nuclear power plants — and 2 international organizations, who discussed methodologies for estimating the cost of such projects and ways to fund them.

In 2018, the Agency conducted six expert missions — to Ghana, Poland and Turkey — to support key organizations in the development of management systems for a nuclear power programme. It also held workshops for Egypt, Kazakhstan and Kenya on modelling human resource requirements and on workforce planning for new nuclear power programmes using its Nuclear Power Human Resources modelling tool.

The Agency continued to update its Country Nuclear Infrastructure Profiles (CNIPs) database, used to monitor the status of nuclear power infrastructure in Member States, and its Integrated Work Plan (IWP) tool, used for integrating Agency support for embarking countries actively developing a nuclear power programme. In 2018, the Agency held meetings with 12 Member States embarking on a nuclear power programme to develop or update their respective IWPs and CNIPs.

The Agency added new 'Legal Framework' and 'Industrial Involvement' modules to its on-line e-learning course based on the Milestones approach for nuclear newcomers. A total of 18 Milestone modules are now available on the Agency's web site.

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Operating Nuclear Power Plants and Expanding Nuclear Power Programmes

At the end of 2018, over 65% of the world’s operating nuclear power reactors had been in operation for longer than 30 years (Fig. 1). While nuclear reactors are typically licensed for 30–40 years, their operating lifespans are being extended significantly through appropriate life management programmes, including special safety reviews and assessments of their essential structures, systems and components. To provide support to its Member States in this area, the Agency published *Economic Assessment of the Long Term Operation of Nuclear Power Plants: Approaches and Experience* (IAEA Nuclear Energy Series No. NP-T-3.25), describing various approaches to techno-economic assessment of the long term operation of a nuclear power plant in its specific market environment. More specific guidance was issued in *Buried and Underground Piping and Tank Ageing Management for Nuclear Power Plants* (IAEA Nuclear Energy Series No. NP-T-3.20), one in a series of publications on assessment and management of ageing of major components of nuclear power plants.

At the first meeting of the Agency’s new Technical Working Group on Nuclear Power Plant Operations in September, 30 senior government officials and industry executives identified priority areas where Agency assistance could help relevant stakeholders improve the economic sustainability of operating nuclear power reactors worldwide. To support Member States in considering future flexible operation of their nuclear power plants, the Agency issued *Non-baseload Operation in Nuclear Power Plants: Load Following and Frequency Control Modes of Flexible Operation* (IAEA Nuclear Energy Series No. NP-T-3.23), providing guidance based on current knowledge and operational experience.

The Agency published *Maintenance Optimization Programme for Nuclear Power Plants* (IAEA Nuclear Energy Series No. NP-T-3.8), sharing proven maintenance optimization methods and techniques essential for the overall performance and competitiveness of nuclear power plants. It also issued *Technical Support to Nuclear Power Plants and Programmes* (IAEA Nuclear Energy Series No. NP-T-3.28), addressing relevant aspects of requesting and obtaining effective technical support and using it appropriately in decision making on nuclear power programmes, projects and plants. Another new Agency publication, *Improvement of Effectiveness of In-Service Inspection in Nuclear Power Plants* (IAEA-TECDOC-1853), investigates the role of effective in-service inspection in maintaining or improving safety and the relationship of improvement and cost. The Agency also published *Dissimilar Metal Weld Inspection, Monitoring and Repair Approaches* (IAEA-TECDOC-1852), outlining good practices, lessons learned, guidance and practical case studies for inspection organizations, operating staff and local suppliers who provide inspection services to utilities.

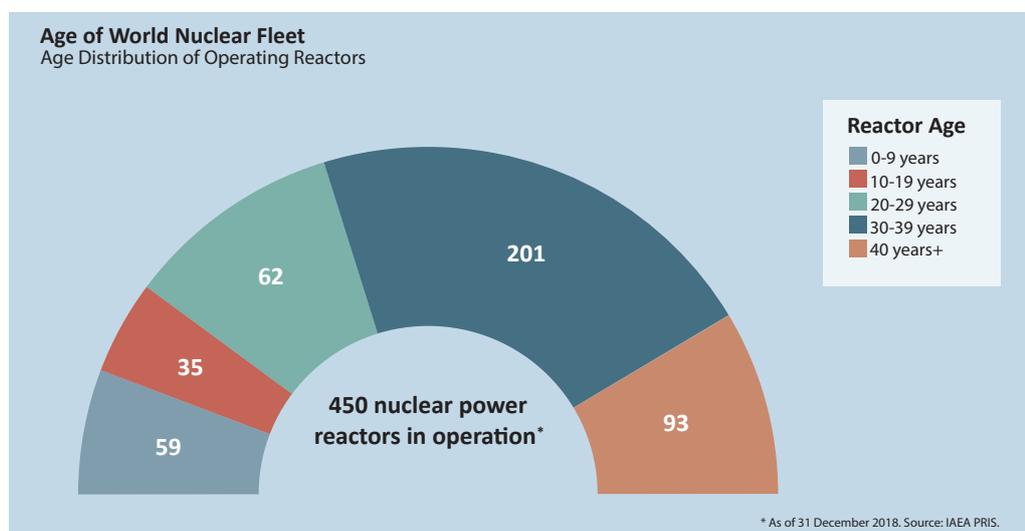


FIG. 1. Age distribution of operating nuclear power reactors as of 31 December 2018.

At the Technical Meeting on Integrated Risk Management: Risk Informed Processes and Programmes during the Lifetime of a Nuclear Power Plant, held in Beijing in July, and the Technical Meeting on Economic Considerations of Asset Management for Nuclear Power Plant Operation and Maintenance, held in Vienna in October, 37 participants from 14 Member States discussed how to extend traditional risk assessments to optimize plant performance. The Agency also held technical meetings related to the optimization of thermal performance, reload core design and core management, and the design modification process at operating nuclear power plants.

Nuclear power plant instrumentation and control remains both an area of rapid technological development, closely linked to facility modernization through digitalization, and an area particularly sensitive to obsolescence and supply chain challenges. In June, the Agency organized a Technical Meeting on Justification of Commercial Industrial Instrumentation and Control Equipment for Nuclear Power Plant Applications, in Toronto, Canada, where 74 participants from 17 Member States shared associated best practices and strategies to improve understanding of the topic. In September, it held a Technical Meeting on Instrumentation and Control Aspects of Human Factors Engineering: Design and Analysis, in Madrid, attended by 56 participants from 23 Member States. The meeting enabled the sharing of best practices and strategies used in the application of human factors engineering principles in the design of human–system interfaces, such as alarms, displays and controls in the plant. The Agency issued two publications related to this topic in 2018: *Approaches for Overall Instrumentation and Control Architectures of Nuclear Power Plants* (IAEA Nuclear Energy Series No. NP-T-2.11) and *Dependability Assessment of Software for Safety Instrumentation and Control Systems at Nuclear Power Plants* (IAEA Nuclear Energy Series No. NP-T-3.27).

To assist Member States in understanding and implementing the commissioning process for a new nuclear power plant or for upgrades or refurbishments of operating nuclear power plants, the Agency issued *Commissioning Guidelines for Nuclear Power Plants* (IAEA Nuclear Energy Series No. NP-T-2.10). The publication describes the commissioning process specific to nuclear power plants, the relevant management system requirements, typical organizational models and critical human resource issues. In August, the Agency held a Technical Meeting on Challenges and Opportunities in the Construction Management of Advanced Nuclear Power Plants in Shanghai, China. The meeting's 47 participants from 19 Member States discussed challenges and opportunities in advanced nuclear power plant construction, changes in industry structure and markets, and strategies and solutions to avoid cost overrun and schedule delay.

“In 2018, the Agency issued the 20th edition of the Country Nuclear Power Profiles (CNPP)”

In 2018, the Agency issued the 20th edition of the *Country Nuclear Power Profiles* (CNPP), a major, publicly available resource on the status and development of nuclear power programmes around the world. The 2018 edition, also available in a mobile version, outlines activities and summaries of 37 countries with developing or established nuclear power programmes.

Human Resource Development, Management and Stakeholder Involvement Support

The Agency's Third International Conference on Human Resource Development for Nuclear Power Programmes: Meeting Challenges to Ensure the Future Nuclear Workforce Capability was held in May in Gyeongju, Republic of Korea. The conference drew more than 500 experts in the areas of capacity building, human resource development, workforce planning, education and training, knowledge management and knowledge networks for nuclear power programmes. Sixty-two Member States and six international organizations were represented. Within the conference, an international student competition provided an opportunity for young students from five Member States to demonstrate innovative ways to educate local communities on the benefits of nuclear science and technology.

The International Conference on Quality, Leadership and Management in the Nuclear Industry–15th FORATOM–IAEA Management Systems Workshop was held in Ottawa in July. More than 350 nuclear industry professionals took part in the conference, which offered focused sessions for owner/operators, regulators and suppliers, and covered a variety of topics including project and quality management, leadership, and organizational and safety culture.

A Technical Meeting on Quality Assurance and Quality Control Activities as Part of a Nuclear Power Plant Management System: Lessons Learned and Good Practices, organized in Vienna in November, provided a forum for discussion of challenges in implementing requirements regarding quality management, quality assurance and quality control activities at nuclear facilities, including oversight of the supply chain. At the meeting, 60 specialists from 26 Member States exchanged their experiences in this area and considered practical solutions to overcome these challenges throughout the life cycle of a facility.

Stakeholder involvement continued to be an important area for countries at all stages of nuclear power development and operation. In 2018, the Agency conducted several expert missions on this topic tailored to the unique needs of individual Member States. It held a new interregional training course on the principles of stakeholder involvement in Vienna in September, with 19 participants from 17 Member States. The course will now be held annually. Also in September, the Agency held a Technical Meeting on Stakeholder Involvement across the Nuclear Power Plant Life Cycle, where 42 participants from 26 Member States and an international organization discussed common challenges as well as trends in and new ways of thinking about stakeholder involvement and public communication.

Nuclear Technology Development

Advanced water cooled reactors

Participants in the coordinated research project (CRP) entitled ‘Methodology for Assessing Pipe Failure Rates in Advanced Water Cooled Reactors’, from ten organizations in eight Member States, developed a research plan for advanced water cooled reactors and an overview of the existing methodologies for pipe reliability analysis in the current fleet. The CRP entitled ‘Probabilistic Safety Assessment (PSA) Benchmark for Multi-Unit/Multi-Reactor Sites’ brings together PSA practitioners from 20 Member States with multi-unit water cooled reactor sites to further develop and test their methodologies for extending existing single-unit PSA analyses and results to a realistic multi-unit site, considering potential scenarios leading to coincidental or consequential damage to multiple cores and spent fuel pools. At the project’s first research coordination meeting, in June, an overall CRP task plan and the work plan for the first year of CRP implementation were developed.

At a Technical Meeting on Hydrogen Management in Severe Accidents, held in Vienna in September, 29 participants from 21 Member States and an international organization discussed hydrogen behaviour during severe accidents and validation and verification of codes, and identified further research and development needs. In October, the Agency conducted a pioneering Technical Meeting on Nuclear–Renewable Hybrid Energy Systems for Decarbonized Energy Production and Cogeneration, where 24 experts from 15 Member States exchanged knowledge on these technology designs and related innovations.

At the Training Workshop on the Development of Severe Accident Management Guidelines Using the IAEA’s SAMG-D Toolkit, held in Vienna from 29 October to 1 November, 27 participants from 20 Member States shared knowledge about developing guidance on the mitigatory actions to be taken during severe accidents in nuclear power plants. This was the fourth such training workshop conducted by the Agency.

The Agency also conducted three national training courses, for Jordan, Saudi Arabia and Sri Lanka, and three interregional training courses on reactor technology assessment to support Member States that are considering or embarking on a new nuclear power

programme. An Excel based toolkit was provided to the Member States to train them in using the Agency's methodology for reactor technology assessment.

The First Joint ICTP-IAEA Course on Scientific Novelties in Phenomenology of Severe Accidents in Water Cooled Reactors was held in Trieste, Italy, in October. Attended by 25 young professionals and engineers from 16 Member States, the course covered a range of topics relevant to the progression of severe accidents in water cooled reactors, including an overview of the associated scientific issues and of technologies designed to cope with such events.

In 2018, the Agency conducted two interregional training courses on severe accidents in water cooled reactors and, using Agency basic principle simulators, three training courses on the physics and technology of advanced water cooled reactors. To support these efforts, the Agency published *Developing a Systematic Education and Training Approach Using Personal Computer Based Simulators for Nuclear Power Programmes* (IAEA-TECDOC-1836), providing an overview of the current status of PC based basic principle simulators and their application in education and training.

Small and medium sized or modular reactors (SMRs)

In response to Member State interest in SMRs, the Agency published *Deployment Indicators for Small Modular Reactors* (IAEA-TECDOC-1854), presenting a methodology that can be used by Member States to evaluate indicators for the possible deployment of SMRs in a national energy portfolio. It also made available the 2018 edition of *Advances in Small Modular Reactor Technology Developments*, a supplement to its Advanced Reactors Information System database. The new edition contains design descriptions for 56 SMRs, provided by 14 Member States.

The first meeting of the new Technical Working Group on Small and Medium Sized or Modular Reactors took place in Vienna in April. Twenty-five representatives of 14 Member States and 2 international organizations identified topical areas of common interest for future collaboration, including development of generic user requirements and criteria; research, technology development and establishment of codes and standards; and design engineering, testing, manufacturing, supply chain and construction.

Fast reactors

The Agency issued two publications on topics related to fast reactors in 2018. The proceedings of the International Conference on Fast Reactors and Related Fuel Cycles: Next Generation Nuclear Systems for Sustainable Development (FR17), held in Yekaterinburg, Russian Federation in 2017, provides a summary of the different technical, plenary and young generation event sessions as well as the speeches delivered during the conference. *Experimental Facilities in Support of Liquid Metal Cooled Fast Neutron Systems* (IAEA Nuclear Energy Series No. NP-T-1.15) provides detailed information on experimental facilities currently in the design phase, under construction or in operation. The publication is a supplement to the Agency's corresponding on-line Catalogue of Facilities in Support of Liquid Metal Cooled Fast Neutron Systems.

The 2018 Joint ICTP-IAEA Workshop on Physics and Technology of Innovative Nuclear Energy Systems (Fig. 2) was attended by 36 young scientists, researchers, engineers and students from 20 Member States. The workshop, held in Trieste, Italy, in August, provided an opportunity to review state of the art reactor design concepts and nuclear fuel cycle options, including design and technological features of various innovative reactor types.

In 2018, the Agency launched two CRPs aimed at improving Member States' analytical capabilities for numerical simulation of sodium cooled fast reactors. The CRP entitled 'Neutronics Benchmark of CEFR Start-Up Tests' will focus on validation of the reactor neutronics simulation codes against recent experimental data measured during physical

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FIG. 2. Participants in the Joint ICTP–IAEA Workshop on Physics and Technology of Innovative Nuclear Energy Systems discuss various design concepts and nuclear fuel cycle options.

start-up of the China Experimental Fast Reactor (CEFR). In the CRP entitled ‘Benchmark Analysis of FFTF Loss of Flow Without Scram Test’, state of the art simulation tools will be used to model multi-physics phenomena. Under the CRP, 25 participants from 13 countries will validate the tools against observations from tests at the Fast Flux Test Facility (FFTF) in the United States of America aimed at demonstrating the reactor’s capability to survive severe unprotected loss of flow accidents.

High temperature reactors

As part of its initiative to preserve the knowledge of high temperature reactors developed in Member States, the Agency organized a Technical Meeting on Knowledge Preservation for Gas Cooled Reactor Technology and Experimental Facilities in Vienna in December. The meeting was attended by 17 participants from 11 Member States, who identified the knowledge of gas cooled reactors and high temperature gas reactors that needs to be preserved, such as reports, records, software codes and information on experimental facilities.

The Agency published a peer reviewed article on the use of heat from high temperature nuclear reactors as an option for energy neutral mineral processing, through the simultaneous extraction of unconventional uranium during primary ore processing. The article, published in the journal *Sustainability* in January, was produced by experts from 16 Member States participating in an ongoing CRP entitled ‘Uranium/Thorium Fuelled High Temperature Gas Cooled Reactor Applications for Energy Neutral and Sustainable Comprehensive Extraction and Mineral Product Development Processes’.

In response to growing Member State interest in molten salt reactor technology, the Agency organized a Technical Meeting on the Status of the IAEA Nuclear Graphite Knowledge Base, held in Vienna in December. At the meeting, 11 molten salt reactor designers and graphite manufacturers from 8 Member States reviewed and updated data in the IAEA Nuclear Graphite Knowledge Base and identified new users of the database and further needs of Member States.

Non-electric Applications of Nuclear Power

In the area of non-electric applications of nuclear power, the Agency published *Examining the Technoeconomics of Nuclear Hydrogen Production and Benchmark Analysis of the IAEA HEEP Software* (IAEA-TECDOC-1859), documenting the results of a CRP completed in 2016. It also launched a new CRP entitled 'Assessing Technical and Economic Aspects of Nuclear Hydrogen Production for Near-term Deployment' with the participation of nine Member States.

A Technical Meeting on the Deployment of Non-Electric Applications Using Nuclear Energy for Climate Change Mitigation was held in Vienna in April. The meeting, with 18 participants from 16 Member States, focused on the future role of nuclear energy for non-electric applications, especially in the heating and transport sectors. At a Technical Meeting to Assess the Prospects of Coupling Non-Electric Applications to High Temperature Nuclear Reactors, held in Vienna in November, 12 participants from 11 Member States discussed the role of nuclear hydrogen production in the future hydrogen economy. In June, the Agency organized a Technical Meeting on Efficient Energy and Water Management in Nuclear Power Plants: Strategies, Policies and Innovative Approaches, where 14 participants from 10 Member States and an international organization reviewed the application of cogeneration — electricity generation and process heat production — for non-electric applications.

During the year, the Agency released an updated version of its Water Management Program (WAMP) software, used for the estimation of water needs in nuclear power plants.

Enhancing Global Nuclear Energy Sustainability through Innovation

The 15th INPRO (International Project on Innovative Nuclear Reactors and Fuel Cycles) Dialogue Forum on Sustainable Supply Chains for Advanced Nuclear Power Systems was held in Vienna in July. Forty-five participants from 28 Member States and 3 international organizations shared information, perspectives and knowledge on issues important to the national, regional and global nuclear supply chains. The 16th INPRO Dialogue Forum on Opportunities and Issues in Non-Electric Applications of Nuclear Energy, held in Vienna in December with 46 participants from 32 Member States and 2 international organizations, focused on technology and institutional aspects of the deployment of non-electric applications of nuclear energy, such as market, resources, effects of regulation and public acceptance issues.

The Agency issued *Enhancing Benefits of Nuclear Energy Technology Innovation through Cooperation among Countries: Final Report of the INPRO Collaborative Project SYNERGIES* (IAEA Nuclear Energy Series No. NF-T-4.9). The publication includes 28 case studies conducted by Member States to identify and evaluate mutually beneficial patterns of cooperation in the nuclear fuel cycle and associated driving forces and impediments.

It also published *Experience in Modelling Nuclear Energy Systems with MESSAGE: Country Case Studies* (IAEA-TECDOC-1837), documenting the experience gained in modelling national and global nuclear energy systems using the Agency's Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE) code through various case studies performed by participating Member States. The feedback from the case studies demonstrated the analytical capabilities of the MESSAGE model and identified possible enhancements for the MESSAGE code and for nuclear energy system modelling.