

# Nuclear Power

## Objective

To assist Member States embarking on new nuclear power programmes in planning and building their national nuclear infrastructures. To provide integrated support to Member States with existing nuclear power plants and to those planning new nuclear build in order to help improve operating performance and help ensure safe, secure, efficient and reliable long term operation through the implementation of good practices and innovative approaches, and lessons learned from the Fukushima Daiichi accident. To provide collaborative frameworks for operators of water cooled reactors to benefit from advances in technology, and for Member States to facilitate effective development of fast reactors and gas cooled reactors and to expand the safe use of non-electric applications.

## Launching Nuclear Power Programmes

In 2016, around thirty Member States were actively considering or planning a nuclear power programme (Table 1). The Agency supported these embarking countries through Integrated Nuclear Infrastructure Review (INIR) missions; workshops and other training opportunities; and tools such as the Country Nuclear Infrastructure Profile and Integrated Work Plan mechanisms.

**TABLE 1. Number of Member States considering or planning a nuclear power programme, according to their official statements (as of 31 December 2016)**

First nuclear power plant started construction/under construction	2
First nuclear power plant ordered	2
Decided to introduce nuclear power and started preparing the appropriate infrastructure	6 <sup>a</sup>
Active preparation for a possible nuclear power programme with no final decision	7
Considering a nuclear power programme	10

<sup>a</sup> Includes Viet Nam, whose National Assembly in November 2016 endorsed the Government's decision to cancel the country's nuclear power plans.

The Agency's INIR missions remained a key element of its assistance to embarking Member States. In 2016, the Agency conducted INIR Phase 1 missions to Malaysia and Kazakhstan, and INIR follow-up missions to Bangladesh and Poland. Since the service's launch in 2009, the Agency has deployed a total of 21 INIR missions to 15 Member States (Table 2). In December, the Agency published *Evaluation of the Status of National Nuclear Infrastructure Development* (IAEA Nuclear Energy Series No. NG-T-3.2 (Rev. 1)), describing the approach to evaluating national nuclear infrastructure development used in INIR missions. The revision takes into account feedback from past INIR missions and self-evaluations, and the lessons from the accident at the Fukushima Daiichi nuclear power plant.

**TABLE 2. Member States that have received INIR missions since the service was introduced in 2009; as of the end of 2016, the Agency had conducted 21 INIR missions**

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

Activities in 2016 focused on increasing Member State awareness and understanding of the 'Milestones' approach to introducing nuclear power, and key issues such as building a national position, road maps for nuclear programme development, management, human resource development, the legal and regulatory framework, and funding and financing. Stakeholder involvement continued to be an important area of attention for countries at all stages of nuclear infrastructure development. The Agency published *Industrial Involvement to Support a National Nuclear Power Programme* (IAEA Nuclear Energy Series No. NG-T-3.4) to assist Member States in establishing national policies and strategies for local industrial involvement and in assessing their available industrial supply options and capabilities, including the national supply chain. A Technical Meeting on the Environmental Impact Assessment Process for Nuclear Power Programmes, organized by the Agency and held in Vienna in May, was attended by 61 participants from 32 Member States. It brought together nuclear and environmental regulators to discuss the challenges in managing the interface between the radiological and non-radiological impact assessment activities ahead of a site licence application.

The Agency standardized the Country Nuclear Infrastructure Profile and Integrated Work Plan mechanisms taking into account the recommendations of INIR missions and the results of technical cooperation projects. The improved mechanisms were used for planning activities in embarking Member States with active nuclear infrastructure development programmes.

Support was provided to Ghana, Kenya, Malaysia, Morocco, Saudi Arabia and the Sudan in conducting studies required for the preparation of a comprehensive report to be used in taking an informed decision on whether to introduce nuclear power into their energy mix. The Agency conducted workshops on nuclear power programme development road maps with Egypt, Saudi Arabia, Sri Lanka and the Sudan, and advised Tunisia and the Sudan on how to prepare the INIR self-evaluation report.

## Operating Nuclear Power Plants and Expanding Nuclear Programmes

The number of operating nuclear power reactors grew to 448 in 2016; 270 of these reactors have been in service for over 30 years. As of the end of 2016, 61 reactors were under construction. The Agency continued to support countries with operating nuclear power plants, mainly by disseminating operational experience and good practices in technology, management and human resources, and by sharing new models, methods, tools and processes for efficient and reliable operation and construction.

Agency activities in this area were expanded to include analysis of specific conditions, cost drivers and reasons for economic challenges, and to identify optimized approaches to technology and management and improvements in existing operational programmes, processes and procedures. The Agency held several meetings on these topics throughout the year, including a Technical Meeting on the Economics of Nuclear Power Plant Life Extension and Long Term Operation held in May at the Agency's Headquarters in Vienna. The meeting drew 23 participants from 18 Member States, who discussed technical and

managerial cost drivers and economic intricacies, and defined major parameters for economic assessment for long term operation of nuclear power plants.

In August, the Agency organized a Technical Meeting on Plant Life Management during the Transition from Operation to Decommissioning of Nuclear Power Plants to help Member States better prepare for planned or premature retirement of nuclear power reactors. Held in Gyeongju, Republic of Korea, the meeting was attended by 75 participants from 13 Member States. Participants identified a number of factors as being critical for a successful transition, including early planning, allocation of dedicated resources in a timely manner, consideration of the significant cultural and organizational changes involved, availability of relevant data and records, and good communication and stakeholder involvement.

At a Technical Meeting on Strengthening Resiliency in Nuclear Power Plant Operations in the Face of Current and Future Challenges held in September in Vienna, 26 executives and leaders of nuclear operating organizations from 10 Member States and 2 international organizations shared experience related to medium and long term challenges in nuclear power plant operation. Participants emphasized the importance of maintaining safety and enhancing the efficiency and effectiveness of nuclear electricity generation. The sixth Nuclear Operating Organization Cooperation Forum, also held in September, during the 60th regular session of the General Conference, gathered together more than 100 industry executives from China, France, the Russian Federation, the United States of America and NUGENIA (Nuclear Generation II & III Association). The participants concluded that, for nuclear power to continue to be sustainable and economically competitive, it is important that operators win and maintain public confidence by paying careful attention to costs and to the management of radioactive waste.

The Agency issued two publications on nuclear power in the IAEA Nuclear Energy Series in 2016. *Technical Challenges in the Application and Licensing of Digital Instrumentation and Control Systems in Nuclear Power Plants* (IAEA Nuclear Energy Series No. NP-T-1.13) presents the technical challenges faced by operators, developers, suppliers and regulators, enabling users, and the industry more broadly, to benefit from shared experience, recent technological developments, and emerging best practices. *Procurement Engineering and Supply Chain Guidelines in Support of Operation and Maintenance of Nuclear Facilities* (IAEA Nuclear Energy Series No. NP-T-3.21) provides an overview of nuclear equipment procurement processes and issues of special concern, as well as guidance on good practices for setting up and managing a high quality procurement organization. A related on-line Nuclear Contracting Toolkit, also published in 2016, was designed to support all levels of procurement activities related to major nuclear power projects, including developing a procurement strategy, proposing and soliciting bids, and negotiating and managing contracts (Fig. 1).



FIG. 1. The Agency's new on-line Nuclear Contracting Toolkit is aimed at supporting Member State procurement activities related to major nuclear power projects.

## Integrated Management Systems

The Agency continued to explore and disseminate good practices and potential improvements in the use of integrated management systems in the operation and construction of nuclear power plants. The strong relationship between quality assurance and management systems, including the supply chain, was discussed at a Technical Meeting held in Vienna in June, attended by 65 participants from 26 Member States and 2 international organizations, and at the joint 14th IAEA–FORATOM Management System Workshop, held in Vienna in December, with over 110 experts from 42 Member States. Both meetings emphasized the importance of the role of nuclear leadership in ensuring safe and economical operation through quality management.

## Capacity Building and Management Support

A major challenge for the nuclear field is to maintain a reliable supply of personnel in order to ensure that a competent workforce is available for all life cycle phases of a nuclear facility. In April, the Agency organized a Technical Meeting, held at the Ringhals Nuclear Power Plant in Sweden, that offered participants practical guidance on improving plant and human performance, and training programmes at nuclear facilities. At a meeting of the Technical Working Group on Managing Human Resources in the Field of Nuclear Energy held in June in Vienna, 21 participants from nuclear facilities, utilities, regulatory bodies and academia, representing 19 Member States, discussed educational programmes, training procedures, workforce productivity and staffing plans. The participants focused on long term and advance planning for human resources management to ensure that the knowledge of staff who are about to retire is preserved.

In 2016, the Agency added two new modules to its on-line E-learning for Nuclear Newcomers series, designed to explain the Agency's 'Milestones' approach. The new modules, on 'Building a National Position' and 'Culture for Safety', bring to 15 the number of interactive modules available on the Agency's web site.

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## Nuclear Technology Development

### *Advanced water cooled reactors*

As a follow-up of the IAEA Action Plan on Nuclear Safety, the Agency organized a Technical Meeting on Phenomenology and Technologies Relevant to In-Vessel Melt Retention and Ex-Vessel Corium Cooling, held in Shanghai, China, in October. Attended by over 60 experts from 18 Member States, the meeting provided a forum for exchanging the most recent research and development results in this area and for discussing strategies and measures to retain melted core in the reactor or the containment vessel. In December, the Agency held a Workshop on Understanding the Role of Severe Accident Management Guidelines to raise awareness of the importance of establishing reliable and systematic guidance on the mitigative actions to be taken in case of a severe nuclear accident. The workshop was attended by 51 participants from 25 Member States and 3 international organizations.

The Agency conducted several other training activities during the year, including a workshop on nuclear technology assessment held in Kenya to assist newcomer countries in evaluating available nuclear power technologies against country specific environments, site requirements and energy needs. Courses on understanding the physics and technology of advanced reactors using PC based simulators were held in the Republic of Korea, Mexico and Tunisia. The Agency expanded the suite of reactor simulators used in the courses to

include a new generic integral pressurized water reactor simulator. A new course on the use of computational fluid dynamics for nuclear power plant design and safety analysis was held in China. The course was attended by over sixty professionals, from 13 institutes in China and from one each in Brazil and South Africa.

The Agency completed the CRP entitled 'Understanding and Prediction of Thermal Hydraulics Phenomena Relevant to Supercritical Water Cooled Reactors', aimed at facilitating collaborative activities to develop the supercritical water cooled reactor concept. This innovative technology was also the focus of two Technical Meetings in 2016: the Technical Meeting on Heat Transfer, Thermal-Hydraulics and System Design for Supercritical Water Cooled Reactors, held in August in Sheffield, United Kingdom, and the Technical Meeting on Materials and Chemistry for Supercritical Water Cooled Reactors, held in October in Řež, Czech Republic.

### *Small and medium sized or modular reactors*

Member State interest in the development of small and medium sized or modular reactors (SMRs) for both electricity generation and non-electric applications continued to grow. To address this growing interest, the Agency held a Technical Meeting on Technology Assessment of Small Modular Reactors for Near Term Deployment in Beijing, China, in September. Using the Agency's methodology, participants conducted a reactor technology assessment of certain types of small modular reactors in order to understand the design and safety features of these systems, including manufacturing issues of structures, systems and components. In December, the Agency held a Technical Meeting on the Design and Operation Aspects of Pressurized Water Reactor Based Small and Medium Sized Reactors in Islamabad, Pakistan, to inform developing countries about the general design features, systems and components of a 300 MW(e) nuclear power reactor. It also issued *Design Safety Considerations for Water Cooled Small Modular Reactors Incorporating Lessons Learned from the Fukushima Daiichi Accident* (IAEA-TECDOC-1785), presenting the operational safety performance of SMR designs for coping with extreme natural hazards.

### *Fast reactors*

The Technical Working Group on Fast Reactors met in Buenos Aires, Argentina, in May to present recent developments in fast reactor technology and to consider future activities in this area. In November, the Agency presented the findings of its review of the recent Generation IV International Forum (GIF) report on safety design guidelines for sodium cooled fast reactors at the Sixth Joint IAEA–GIF Technical Meeting/Workshop on the Safety of Sodium Cooled Fast Reactors. During the year, the Agency launched the LMFNS (Liquid Metal Cooled Fast Neutron Systems) Facilities Database, offering Member States detailed information on experimental facilities in support of the development of fast neutron systems.

A four year CRP entitled 'Benchmark Analyses of an EBR-II Shutdown Heat Removal Test' was concluded at a final Research Coordination Meeting held in April. The CRP contributed to the verification and validation of Member State simulation tools to be used for the design and safety analysis of sodium cooled fast reactors. A new CRP entitled 'Radioactive Release from the Prototype Fast Breeder Reactor under Severe Accident Conditions' was launched at a Research Coordination Meeting in May. The CRP will help Member States to better understand the phenomena involved in a severe accident in a sodium cooled fast reactor and to develop the corresponding simulation tools. The Joint ICTP–IAEA Workshop on Physics and Technology of Innovative Nuclear Energy Systems for Sustainable Development conducted in August–September at the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy, attracted 47 participants from 24 Member States. The workshop presented the theoretical foundation of all aspects



of innovative nuclear energy systems and familiarized students with their models and codes for design and safety analysis.

### *High temperature reactors*

Agency activities in the area of high temperature gas cooled reactors included evaluations of technology readiness, safety requirements, high fidelity tools and sustainability aspects. As part of its initiative to preserve the high temperature reactor knowledge developed over many decades at the Jülich Research Centre, Germany, the Agency conducted a mission to assess requirements for transferring knowledge, documents and software from the Centre to the Agency. Most of this knowledge is related to safety aspects of high temperature reactors.

The Agency held its first Technical Meeting on the Status of Molten Salt Reactor Technology in October. The meeting's high attendance — 35 participants from 17 Member States — reflected the strong interest in Agency support in this area.

## **Advanced Reactors Information System (ARIS)**

In July, the Agency released a new version of its on-line Advanced Reactors Information System (ARIS) database, with a specific section dedicated to SMRs and the incorporation of innovative molten salt reactors. A booklet on advances in SMR technology developments was published in August, as a supplement to ARIS.

## **Non-electric Applications of Nuclear Power**

In line with General Conference resolution GC(58)/RES/12 on “Strengthening of the Agency’s technical cooperation activities” and in response to the growing interest in nuclear cogeneration and process heat for nonelectric applications, the Agency provided support to Member States interested in seawater desalination, hydrogen production, district heating and other industrial applications of nuclear energy. In May, it held the Fifth Meeting of the Technical Working Group on Nuclear Desalination, with 13 participants from 11 Member States. It also organized three Technical Meetings on topics related to the vendor–user interface, techno-economics and socioeconomics of non-electric applications of nuclear energy. A third and final Research Coordination Meeting completed the CRP entitled ‘Application of Advanced Low Temperature Desalination Systems to Support Nuclear Power Plants and Non-electric Applications’. Participants were asked to provide contributions for a TECDOC, which will serve as a collection of best practices and proven methods for strengthening the design and development of advanced low temperature desalination processes coupled to nuclear power reactors.

## **Enhancing Global Nuclear Energy Sustainability through Innovation**

With Mexico joining in 2016, the membership of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) grew to 42. During the year, Indonesia completed a Nuclear Energy System Assessment (NESA) report on its large light water reactor scenario.

The Agency carried out several INPRO related training activities, including a Regional Training Course on Nuclear Energy System Modelling and Assessment Using the INPRO Methodology, held in April in Rabat, Morocco. The course was attended by 23 participants from 11 Member States. Three Technical Meetings held in Vienna in June, October and

November, with 44 participants from 43 Member States, focused respectively on INPRO collaborative projects on roadmaps to innovative nuclear energy systems, key indicators of innovative nuclear energy systems, and cooperative approaches to the back end of the nuclear fuel cycle. At two Technical Meetings held in Vienna in May and November, involving 47 participants from 35 Member States, experts reviewed updates of the INPRO methodology manuals in the areas of environmental impacts of resource depletion and stressors, and safety of nuclear reactors and fuel cycles. GIF and the Agency held an interface meeting in Vienna in April. The 30 participants from 9 GIF member countries reviewed progress on innovative reactors and related assessment methodologies.

The Agency issued two publications updating the INPRO Manuals: *INPRO Methodology for Sustainability Assessment of Nuclear Energy Systems: Environmental Impact from Depletion of Resources* (IAEA Nuclear Energy Series No. NG-T-3.13) and *INPRO Methodology for Sustainability Assessment of Nuclear Energy Systems: Environmental Impact of Stressors* (IAEA Nuclear Energy Series No. NG-T-3.15). In March, it issued *Modelling Nuclear Energy Systems with MESSAGE: A User's Guide* (IAEA Nuclear Energy Series No. NG-T-5.2), providing detailed guidance on building mathematical models representing complex nuclear energy systems within the framework of the Agency's Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE).

Two INPRO Dialogue Forums were held in 2016. The 12th INPRO Dialogue Forum, held in Vienna in April, provided an opportunity for GIF to present Generation IV nuclear energy systems to Member States. The 13th INPRO Dialogue Forum, held in Vienna in October, considered legal and institutional issues of global deployment of small modular reactors. It presented case studies on how existing frameworks such as international legal instruments and regulatory regimes may relate to the specific case of factory built or factory fuelled reactors. These two Forums attracted more than 130 experts from over 35 Member States and the European Commission, the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development, the International Framework for Nuclear Energy Cooperation and the World Nuclear Association.