# NUCLEAR TECHNOLOGY

## Nuclear Power, Fuel Cycle and Nuclear Technology

### *Status and trends*

At the end of 2021, the world's total nuclear power capacity was 389.5 gigawatts (electrical) (GW(e)), generated by 437 operational nuclear power reactors in 32 countries. During the year, over 5.2 GW(e) of new capacity was connected to the grid, from 4 pressurized water reactors and 1 pressurized heavy water reactor and 1 high-temperature reactor. During 2021, 8.7 GW(e) of capacity was retired, with the permanent shutdown of ten nuclear power reactors. Supplying 2653.1 terawatt-hours of greenhouse gas emission-free electricity, nuclear power accounted for about 10% of total global electricity generation and more than a quarter of the world's low carbon electricity production. At the end of the year, 58.1 GW(e) of capacity was under construction, comprising 56 reactors, including 10 reactors (8.8 GW(e)) where construction started in 2021.

In 2021, the Agency revised up its high case projection of the potential growth of nuclear power capacity for the first time since the Fukushima Daiichi accident in 2011. It showed a more than doubling of the currently installed capacity (394.5 GW(e)) to 792 GW(e), corresponding a 12.3%. share of global electricity production compared with the current 10%. The low case estimate saw global nuclear power capacity essentially unchanged at 394 GW(e), with nuclear power's share of global electricity generation falling to 6.3%.

### *International conferences*

At the 28th IAEA Fusion Energy Conference (FEC 2020), key physics and technology issues around the use of nuclear fusion as a future source of energy were discussed. The Conference, attended virtually by over 4000 participants from 119 Member States, also saw the release of the upgraded IAEA Fusion Device Information System, which includes general and technical information on 134 public or private fusion devices with experimental and demonstration designs, currently in operation, under construction or being planned.

The Agency's International Conference on Radioactive Waste Management: Solutions for a Sustainable Future brought together some 900 participants from 92 Member States. At the conference, it was confirmed that existing solutions can be implemented for all types of radioactive waste, and it was recommended that early planning can improve efficiency and contribute to the sustainability of nuclear power and nuclear applications.

### *Energy assessment services*

The Agency continued to assist Member States in energy planning to address sustainable development and climate change mitigation. It hosted 26 training events for specialists in Africa, Asia, Europe, and Latin America and the Caribbean on evaluating their energy needs including by using the Agency's energy assessment tools.

To improve understanding of the contribution of different energy sources to decarbonization in complex electricity systems, the Agency developed the Framework for the Modelling of Energy Systems (FRAMES), an integrated power system modelling tool that quantifies the value that nuclear brings to low carbon systems. FRAMES evaluates impacts on emissions, generation mix and cost of electricity. It also helps identify optimal grid integration of advanced technologies such as small modular reactors as well as non-electric applications of nuclear energy.

## *The Agency at the 2021 United Nations Climate Change Conference*

Led by Director General Grossi, the Agency's high-profile presence at the 26th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP26) helped ensure that, for the first time, nuclear power gained a prominent place at the world's main forum on climate change and the transition to clean and reliable energy.

The Agency contributed to the COP26 debate through its unique science and evidence based approach, showing how nuclear technology is vital in both fighting the climate crisis and addressing its consequences.

In cooperation with countries and other international partners, the Agency participated in some 20 COP26 events. As the host country, the United Kingdom, along with France, the Russian Federation and the United States of America, fostered discussions on the importance of nuclear power in decarbonizing the energy system, including through joint events with the Agency. On climate change adaptation, the Agency organized and supported events on climate-smart agriculture, water resources management and ocean sciences.

Ahead of COP26, the Agency released two publications: Nuclear Energy for a Net Zero World, which highlighted the key contributions that nuclear energy makes to decarbonizing the energy system, and Nuclear Science and Technology for Climate Adaptation and Resilience, which showed how nuclear applications support sustainable land and water management, climate-smart agriculture, and the analysis and monitoring of emissions and changes in the environment.

In March 2021, the Agency launched a digital public information campaign on nuclear for climate change, to help build momentum. It had reached 9.8 million people across all platforms by the end of COP26.

*At COP26 in Glasgow, Scotland, Director General Grossi discusses how the world can manage to overcome the climate crisis.*

### *Support to operating nuclear power plants*

The Agency's on-line Training Course on Nuclear Supply Chain Management and Procurement enabled Member States to learn about good practices for managing procurement and supply chain activities related to the construction, operation and maintenance of nuclear power plants (NPPs). The course was implemented utilizing the Agency's relevant virtual toolkits.

### *Launching nuclear power programmes*

The Agency continued its assistance to newcomer countries despite the challenges caused by the COVID-19 pandemic. It conducted an Integrated Nuclear Infrastructure Review (INIR) Phase 1 mission to Uganda, an INIR Phase 2 mission to Uzbekistan and an INIR Phase 1 follow-up mission to Kenya (Fig. 1). The Agency also delivered the final INIR report to Uzbekistan during the 65th regular session of the General Conference.

*FIG. 1. Completion of INIR Phase 1 follow-up mission to Kenya.*

### *Capacity building, knowledge management and nuclear information*

The Agency conducted nine Nuclear Energy Management (NEM) and Knowledge Management (NKM) Schools. That included two annual joint NEM–NKM Schools, with the Abdus Salam International Centre for Theoretical Physics; and seven NEM and NKM Schools, in Belgium with the European Nuclear Education Network, in China, in Japan, at the European Nuclear Young Generation Forum (ENYGF) in Spain, two in the Russian Federation and one in Uzbekistan (Fig. 2).

The Agency conducted nine Knowledge Management Assist Visit (KMAV) virtual missions, to Brazil, Hungary, Jordan, Mexico, Sudan and Uzbekistan, as well as three to Indonesia, reviewing their knowledge management programmes and providing recommendations for enhancement.

*FIG. 2. Participants in the ENYGF NEM School in Spain.*

Over the year, 124 371 new records were added to the International Nuclear Information System (INIS). This includes 16 251 full text documents. The INIS repository was accessed by over 2.4 million users, who viewed 5.6 million pages and performed 3.6 million unique searches. This was the largest number of annual users in the 50-year history of INIS and represented a 52% increase compared with the previous year.

### *Stakeholder involvement*

The Agency supported Member States in their stakeholder engagement efforts by conducting customized interregional workshops and topical webinars, as well as various training courses, schools and peer reviews. It also released Stakeholder Engagement in Nuclear Programmes (IAEA Nuclear Energy Series No. NG-G-5.1), the first IAEA Nuclear Energy Series Guide-level publication to support national efforts to engage with stakeholders throughout the life cycle of nuclear facilities.

### *Assurance of supply*

The IAEA Low Enriched Uranium Bank in Kazakhstan, which became operational in 2019, continued safe operations at the Ulba Metallurgical Plant.

A low enriched uranium reserve in Angarsk, established following the agreement of February 2011 between the Government of the Russian Federation and the Agency, remained operational.

### *Fuel cycle*

The publication Spent Fuel Performance Assessment and Research: Final Report of a Coordinated Research Project (SPAR-IV) (IAEA-TECDOC-1975) provides an overview of the technical issues related to wet and dry storage of spent fuel and presents the main results and findings from a related coordinated research project (CRP).

### *Reactor technology development and innovation*

To support research and development on integrated, sustainable energy system designs and modelling focused on small modular reactors and microreactors as well as renewable

energy technologies for multipurpose applications, the Agency designated Ontario Tech University in Canada as a Collaborating Centre for integrated energy systems with advanced nuclear power reactors.

To support the development of common industrial approaches by technology holders and users' requirements and criteria by operators, the Agency started two parallel projects 'Generic User Requirements and Criteria (GURC) of Small Modular Reactor Technologies for Near Term Deployment' and 'Codes and Standards, Design Engineering and Manufacturing of Components of Small Modular Reactors'. In 2021, the related activities were integrated within new Agency-wide initiatives on harmonization and standardization for advanced reactors and the Platform on Small Modular Reactors and their Applications (see related box).

The Agency held webinars highlighting the role of international collaboration in developing and deploying new nuclear power technologies focusing on topics such as enhancing the technological competitiveness of SMRs for near term deployment and the potential role of microreactors.

### *Research reactors*

The Agency upgraded its Research Reactor Database to offer enhanced functionality for users.

The Agency resumed Integrated Nuclear Infrastructure Review for Research Reactors missions with in-person participation of many stakeholders. The first such mission since the beginning of the COVID-19 pandemic assisted Thailand.

### *Launch of the Agency-wide Platform on Small Modular Reactors and Their Applications*

As elaborated in *Technology Roadmap for Small Modular Reactor Deployment* (IAEA Nuclear Energy Series No. NR-T-1.18), published in 2021, global interest in small modular reactors (SMRs) has been increasing due to their potential for flexible power generation for a wider range of users and applications, and as a replacement for ageing fossil fuel-fired power plants. They are also expected to offer enhanced safety features, lower upfront costs and suitability for cogeneration and non-electric applications. In addition, SMRs may offer options for remote regions and for nuclear–renewable hybrid energy systems.

To respond to the growing interest, the Agency-wide Platform on SMRs and their Applications was established to coordinate the Agency's activities on SMRs and provide 'one-stop shop' support for Member States and stakeholders. The Platform brings together all Agency expertise on the development, early deployment and oversight of SMRs and their applications in an effective and efficient manner, providing comprehensive managerial and technical support.

In its first year, the Platform was tasked with developing a medium term strategy (2022–2027) for support for Member States, and an SMR Coordination and Resource Portal for Information Exchange, Outreach and Networking. It also prepared a broad proposal for an interregional project under the technical cooperation programme entitled 'Supporting Member States' Capacity Building on Small Modular Reactors and Microreactors and their Technology and Applications — A Contribution of Nuclear Power to the Mitigation of Climate Change'. The Platform is now developing a high-level publication provisionally entitled *Small Modular Reactors: A New Nuclear Energy Paradigm*, which will summarize the enabling factors to be considered by policymakers in the decision and deployment phases for SMRs. It has also begun addressing the first requests for support received from Member States.

The Agency and the Reactor Institute Delft in the Netherlands expanded cooperation in neutron activation analysis (NAA) to neutron-beam based methodologies, a key technique in materials research, biology and medicine. To this end, the Agency re-designated the institute as a Collaborating Centre for NAA and neutron-beam based methodologies.

The Agency continued to expand its suite of remote tools for capacity building using research reactors and for sustainable operation and effective utilization of research reactors. Two Internet Reactor Laboratories, hosted in the Czech Republic and the Republic of Korea, started transmission of experiments to students (Fig. 3). Two e-learning courses were expanded, and a new course was launched.

## *Radioactive waste management*

The Agency designated the Beijing Research Institute of Uranium Geology in Beishan, China as a Collaborating Centre, the first such Centre in the field of geological disposal of high level waste (HLW). Given the ongoing development of underground research laboratories (URLs) worldwide, the Collaborating Centre will contribute to international research on safe disposal of HLW (see related case study).

The Agency's Spent Fuel and Radioactive Waste Information System (SRIS) aims to facilitate information sharing and simplify national reporting in a single, easy-to-use platform. During 2021, Member States shared data on spent fuel and radioactive waste management through SRIS, which is hosted on the Agency's public web site. Development of the SRIS was achieved in close cooperation with the European Commission and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development.

## *Decommissioning and environmental remediation*

The Agency established a Technical Working Group on Decommissioning and Environmental Remediation, whose first meeting focused on the interface between the regulator and the operator, use of new and advanced technologies for decommissioning and environmental remediation, global status and trends in decommissioning, and sharing of information on successful remediation projects.

## *Nuclear fusion*

The Agency launched a new project entitled 'Synergies in Technology Development between Nuclear Fission and Fusion for Energy Production' identifying areas where fission technology can benefit fusion technology development and advising on how this knowledge can be transferred and shared.

*FIG. 3. Transmission of a research reactor experiment by the Internet Reactor Laboratory.*

The seventh Demonstration Fusion Power Plant (DEMO) Programme Workshop, a platform to facilitate international collaboration on defining and coordinating DEMO programme activities, held virtually, identified good practices on regulation of future nuclear fusion power plants, including aspects of safety and security, radioactive waste management and considerations for safeguards.

### *Nuclear data*

The Agency improved its nuclear data libraries used for verification purposes by updating the IAEA Handbook of Nuclear Data for Safeguards with fission yield information and improved (alpha.n) nuclear reaction data for criticality issues in both nuclear power and safeguards applications.

### *Accelerator technology and its applications*

The Agency and the University of Paris-Saclay in France established a strategic partnership to enhance the use of nuclear technology in the field of characterization and preservation of cultural and natural heritage. The university has become the first Atoms for Heritage Collaborating Centre.

The Agency and South Africa's iThemba Laboratory for Accelerator-Based Sciences (iThemba LABS), agreed to jointly promote and strengthen the use of accelerator-based science, technology and applications. As a result, iThemba LABS was designated as a Collaborating Centre in the area of accelerator-based scientific research and applications.

### *Nuclear instrumentation*

The Agency designed, constructed and commissioned its deuterium–deuterium based neutron generator as part of the Neutron Science Facility in Seibersdorf, Austria (Fig. 4). This new state of the art infrastructure will offer training and practical applications with neutrons. These include demonstration experiments, such as neutron activation analysis, neutron radiography/tomography, delayed neutron counting, neutron detection experiments as well as radiation protection practices.

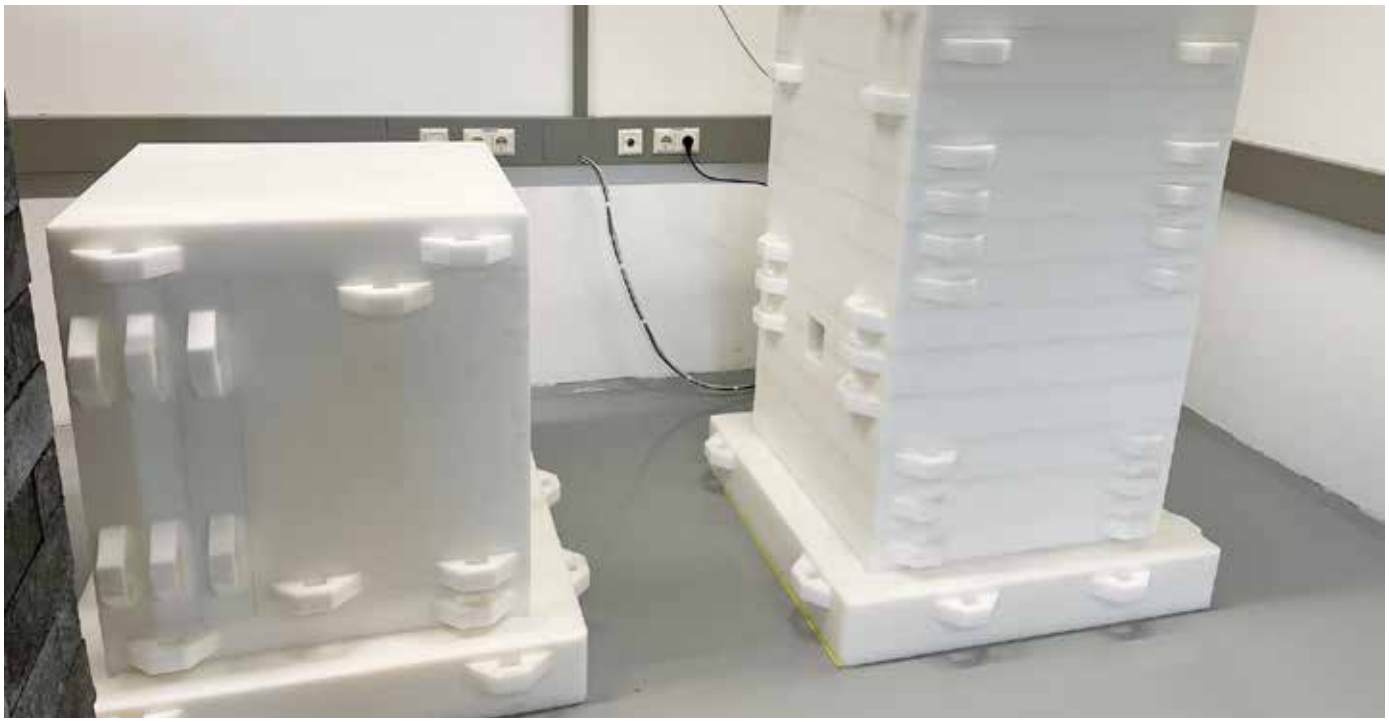

*FIG. 4. The shielding assembly housing the deuterium–deuterium neutron generator during its commissioning phase.*