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# Nuclear Science

## Objective

*To support Member States in strengthening capabilities in the development and application of nuclear science as a tool for their technological and economic development. To assist Member States in enhancing sustainable operation, including effective utilization of research reactors, in implementing new research reactor projects and nuclear capacity building programmes, based on access to research reactors.*

## Nuclear Data

Nuclear physics experts can now coordinate their efforts to develop better nuclear reaction data tables through the Agency's new International Nuclear Data Evaluation Network (INDEN). Launched in 2018, INDEN is expected to stimulate advances in neutron cross-section evaluation of nuclides that are particularly relevant to nuclear technologies. Within INDEN, experts can collaborate on innovative measurements and model simulations to come to the best possible nuclear reaction data tables for light nuclides such as carbon and nitrogen, structural materials such as chromium and nickel, and important actinides such as the plutonium isotopes.

The Agency's Nuclear Data Services portal continued to host key nuclear data libraries for both power and non-power applications. Additions in 2018 included the JENDL Photonuclear Data File 2016 (JENDL/PD-2016) and the JENDL Activation Cross Section File for Nuclear Decommissioning 2017 (JENDL/AD-2017), both released by Japan.

The Agency organized a crowdsourcing challenge aimed at analysing computer simulated damage to a fusion reactor wall exposed to high temperatures and bombardment by highly energetic neutrons and other particles. The challenge was won by a team of scientists from the Max Planck Institute for Plasma Physics and the Max Planck Computing and Data Facility in Garching, Germany, whose molecular dynamics approach simulated this the most efficiently (Fig. 1).

## Research Reactors

### *Utilization and applications of research reactors*

The Agency carried out proficiency testing involving 41 neutron activation analysis laboratories in 29 Member States through an interlaboratory comparison that provided evidence of the validity of their measurement results. In October, it organized a Training Workshop on E-learning Tools for Neutron Activation Analysis, with 28 participants from 22 Member States, as well as an expert mission to evaluate the current status of the neutron activation analysis facility at the Jordan Research and Training Reactor.

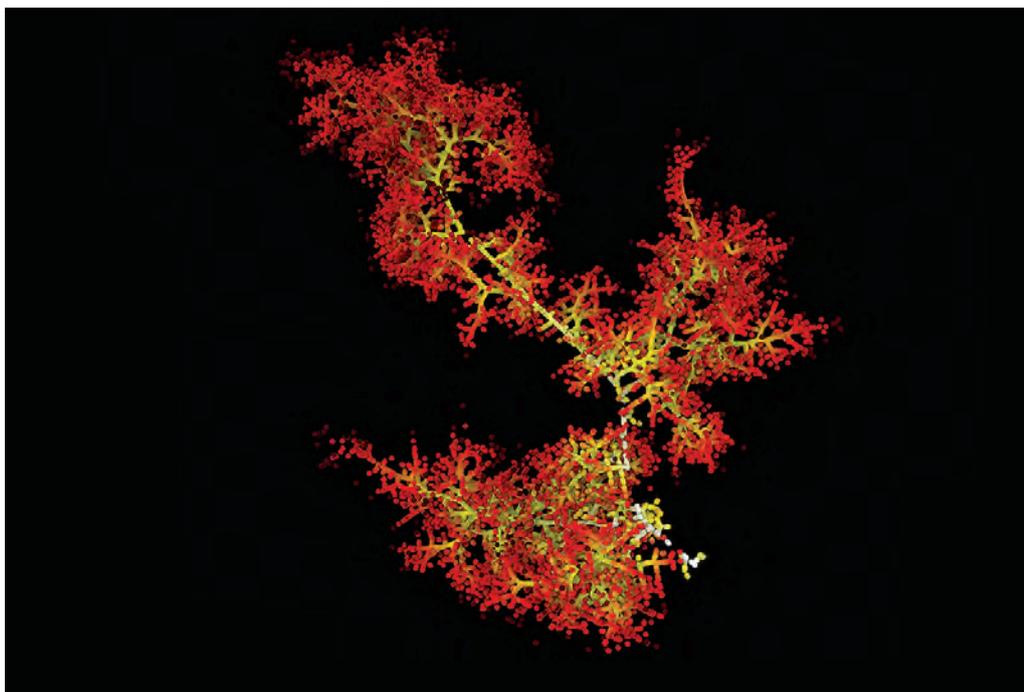


FIG. 1. Representation of a molecular dynamics simulation of damage to a fusion reactor wall from the Max Planck Institute for Plasma Physics, Germany. (Photograph reproduced courtesy of Max Planck Institute for Plasma Physics, Germany.)

The Agency initiated a round robin test of contrast and resolution in 2-D and 3-D neutron imaging, in cooperation with the Paul Scherrer Institute. Five participants from five Member States had completed measurements by the end of the year. This effort marks the first steps toward international standards in the area of digital neutron radiography and tomography.

In October, the Technical Meeting on the Safety and Utilization of Subcritical Assemblies, held in Vienna, brought together 17 experts from 14 Member States to discuss issues related to the safe management and effective use of such facilities, including associated challenges, experiences and good practices. Participants also exchanged experiences in the application of the Agency's safety requirements for research reactors to subcritical assemblies.

A Training Workshop on Expansion of the Research Reactor Stakeholder Base through Strategic and Business Plans focused on methodologies for developing strategies and action plans to re-evaluate stakeholder needs and define new research reactor applications to expand their use. The workshop, held in Vienna in November, provided training to 25 participants from 18 Member States. Also in November, in cooperation with the Asia–Oceania Neutron Scattering Association (AONSA) and the Australian Nuclear Science and Technology Organisation (ANSTO), the Agency organized the AONSA 2018 Neutron School, in Sydney, Australia. The school provided young scientists with an introduction to neutron scattering techniques through hands-on experiments and data analysis conducted using instruments at the ANSTO.

The Agency issued two publications presenting the results of completed coordinated research projects (CRPs) on neutron activation analysis: *Advances in Neutron Activation Analysis of Large Objects with Emphasis on Archaeological Examples* (IAEA-TECDOC-1838) and *Development of an Integrated Approach to Routine Automation of Neutron Activation Analysis* (IAEA-TECDOC-1839).

## *New research reactor projects, infrastructure development and capacity building*

*“The first two INIR-RR missions were conducted in 2018”*

The Agency’s new Integrated Nuclear Infrastructure Review for Research Reactors (INIR-RR) peer review service assists Member States in the development of infrastructure for nuclear research reactors. The first two INIR-RR missions were conducted in 2018 – to Nigeria in February, and to Viet Nam in December. The final INIR RR mission report was delivered to Nigeria in December.

The Agency organized two workshops on its Milestones approach for a new research reactor project and on preparing for an INIR-RR mission. The first workshop, held in Zambia in September, was attended by about 20 representatives of governmental, public and private organizations; the second workshop, held in Thailand in November, provided information for around 50 representatives of various stakeholder organizations. A Training Workshop on the IAEA’s Research Reactor Milestones Approach and on the Establishment of the Infrastructure for a New Research Reactor was held in October in Vienna, with 20 participants from 13 Member States, representing reactor operators, regulators, designers and vendors. The workshop focused on sharing experiences, challenges and lessons learned in the development and implementation of new research reactor projects. Thailand also hosted an expert mission on site evaluation for a new research reactor.

During the year, the Agency consolidated and expanded its instruments and tools: the Internet Reactor Laboratory, a distance training tool mainly for academic education (broadcasting sessions continued in 2018 for the Africa, Europe, and Latin America and the Caribbean regions); the Research Reactor Regional Schools (RRRSs), for basic training; the Eastern European Research Reactor Initiative (EERRI) for advanced hands-on training, mainly for young professionals; and the IAEA-designated International Centre based on Research Reactor (ICERR) scheme for specific, advanced training for young and senior professionals. In June, a Technical Meeting on the Role of Research Reactors in Human Capacity Building in Support of Nuclear Technology enabled 30 participants from 22 Member States to share their experiences using hands-on training at research reactors as a tool for the development and preservation of practical nuclear competencies.

The Agency provided support for the 14th Eastern European Research Reactor Initiative fellowship training course, which took place in Vienna and Prague from 24 September to 2 November. The course provided ten participants from six Member States with the necessary background to carry out activities related to the planning, commissioning, safe operation, maintenance and effective utilization of research reactors.

A new Agency publication issued in 2018, *Feasibility Study Preparation for New Research Reactor Programmes* (IAEA Nuclear Energy Series No. NG-T-3.18), describes considerations concerning the justification for a new research reactor, associated key nuclear infrastructure issues, cost-benefit analysis and risk management that should be addressed prior to authorization of a new research reactor project.

### *Research reactor fuel cycle*

The Agency continued to provide support for the project to convert Nigeria’s only operating research reactor, a miniature neutron source reactor (MNSR), from high enriched uranium (HEU) fuel to low enriched uranium (LEU) fuel and to return the HEU fuel to China. The project was successfully completed in December (Fig. 2). During the year, the Agency held two technical meetings on related topics. The ninth annual Technical Meeting on the Conversion of Miniature Neutron Source Reactors from High Enriched Uranium to Low Enriched Uranium Fuel, in Abuja, provided an opportunity for 21 participants from 6 countries to share lessons learned and discuss technical challenges related to MNSR conversion and HEU repatriation projects. At the 12th Technical Meeting on Lessons Learned from High Enriched Uranium Take-back Programmes, held in Beijing, 81 participants from



FIG. 2. Workers loading the HEU fuel into a container for transportation from Nigeria to China in December.

19 Member States shared information about the technical, legal, logistical, administrative and other challenges they had encountered in preparing and performing shipment operations, in order to facilitate planning for future shipments and to help avoid potential delays.

Technical experts and policy makers exchanged information about recent developments and prospects for further HEU minimization efforts at the third International Symposium on HEU Minimization. The symposium, organized by the Agency in cooperation with the Norwegian Ministry of Foreign Affairs and the Norwegian Radiation Protection Authority, was held in Oslo in June.

In November, the Agency supported the International Meeting on Reduced Enrichment for Research and Test Reactors, organized by the United States Department of Energy's National Nuclear Security Administration under its material management and minimization conversion programme. Held in Edinburgh, the meeting was attended by 148 participants from 22 Member States. Participants shared information on and experience with LEU fuels, conversion analysis studies and licensing of converted research reactors.

In October, 25 current and prospective producers of molybdenum-99 (Mo-99) from 11 Member States took part in a Technical Meeting on Global Capabilities for the Production and Manufacture of Non-High Enriched Uranium Mo-99 Targets. The participants shared experiences and discussed developments in the manufacture of non-HEU isotope production targets.

In November, the Agency held a Training Workshop on Research Reactor Spent Fuel Management in Vienna, where 38 owners, operators, designers and regulators of research reactors from 24 Member States exchanged information, experiences and knowledge relevant to spent fuel management.

### *Research reactor operation and maintenance*

In March, the Agency conducted an Operation and Maintenance Assessment for Research Reactors (OMARR) mission to Uzbekistan's WWR-SM research reactor, aimed at improving operational and maintenance practices at the facility. Another OMARR mission was conducted in November to the TRIGA research reactor of the Bangladesh Atomic Energy Commission (BAEC). The mission team provided recommendations and suggestions to support BAEC in its preparation of an action plan to ensure efficient and

reliable operation of its research reactor for the next 15–20 years. In May, the Agency conducted a pre-OMARR mission to the TRICO-II research reactor in the Democratic Republic of the Congo, identifying areas requiring thorough review during the main mission.

The Agency organized two training workshops in the area of research reactors during the year. The Training Workshop on Online Monitoring, Non-Destructive Examination and In-Service Inspection of Research Reactors, held in Vienna in June and attended by 23 participants from 21 Member States, was aimed at improving practical competences in this field. The Workshop on Decommissioning Planning for Research Reactors, held in Vienna in August with 37 participants from 32 Member States, focused on the need to create a decommissioning plan while developing a reactor design and to update the plan during the reactor's operation.

In October, a Technical Meeting on Good Practices for the Operation and Maintenance of Research Reactors, with 30 participants from 26 Member States, provided a forum for the exchange of information, experiences and practical knowledge aimed at enhancing the performance, safety and reliability of such facilities.

The Agency organized a training course on the operation and maintenance of research reactors for the Latin America and the Caribbean region, held in Santiago in October. The 12 participants from 6 Member States also evaluated the Agency's relevant training materials to identify possible adjustments or improvements for future training courses on the same topic.

In November, an expert mission to Bangladesh carried out non-destructive examination and in-service inspection of the BAEC TRIGA research reactor. The Agency provided an underwater camera for visual inspection of reactor components located in the reactor pool.

## Accelerator Applications

*Accelerator Simulation and Theoretical Modelling of Radiation Effects in Structural Materials* (IAEA Nuclear Energy Series No. NF-T-2.2), a new Agency publication issued in 2018, summarizes the key results of a CRP on the development of advanced radiation resistant structural materials for use in innovative nuclear systems. Nineteen leading nuclear research and development organizations from 15 Member States took part in the multi-year project.

In June, the Agency launched a new CRP entitled 'Facilitating Experiments with Ion Beam Accelerators'. The five year project will provide access to ion beam facilities for researchers from developing Member States without accelerators for analytical and irradiation purposes, as well as for hands-on training courses.

In October, a Technical Meeting on Advanced Methodologies for the Analysis of Materials in Energy Applications Using Ion Beam Accelerators, in Vienna, brought together 23 experts from 15 Member States. Participants discussed the current status of the techniques employed at ion beam accelerators to irradiate and analyse materials relevant to fast spectrum power reactors as well as future fusion reactors.

At a Technical Meeting on Novel Multidisciplinary Applications with Unstable Ion Beams and Complementary Techniques, organized in Vienna in December, 22 experts from 12 Member States discussed recent advances in unstable beam production and acceleration technologies, as well as various applications of radioactive ion beams, from materials research to radioisotope production.

Together with the Abdus Salam International Centre for Theoretical Physics (ICTP), the Agency organized a Joint ICTP-IAEA Advanced School on Ion Beam Driven Materials Engineering: Accelerators for a New Technology Era in Trieste, Italy, in October. The school highlighted the latest technological developments for engineering new material properties with ion beams, focusing in particular on quantum technologies. Twenty-five PhD students and early career researchers from 15 Member States took part.

In October, at the first Research Coordination Meeting of a CRP entitled ‘Ion Beam Irradiation for High Level Nuclear Waste Form Development (INWARD)’, 15 experts from 8 Member States discussed the use of ion beams to produce accelerated damage of waste forms in order to analyse and predict the behaviour of high level nuclear waste under different storage conditions. The results will be used to define the source terms for waste forms in evolving repository designs, thus enhancing the design and reducing uncertainty and costs.

The Agency’s Accelerator Knowledge Portal was updated to include five different types of research infrastructure: electrostatic accelerators, synchrotron light sources, spallation neutron sources, neutron scattering instruments and X ray free electron lasers. In 2018, the portal was visited by 3135 users from 111 Member States.

The Agency published an article entitled ‘IAEA fosters nuclear analytical techniques for forensic science’ in the journal *Forensic Chemistry*. The paper focuses on the use of ion and neutron beam techniques for elemental and molecular analysis and on the Agency’s role in coordinating the development of different techniques in the area of forensics. This article also served as an introduction to eight individual Member State publications on the same topic.

In October, the Agency organized a Technical Meeting on Guidelines for the Establishment and Optimization of Cold Neutron Sources in Research Reactor and Accelerator Facilities, aimed at producing a report on operating experience and the outlook for the development of cold neutron moderators, including design details and safety considerations. The meeting, held in Vienna, was attended by 26 participants from 13 Member States.

The Agency completed a comprehensive feasibility study for the establishment of a compact ion beam accelerator at its laboratories in Seibersdorf. The study was based on an extensive survey involving over 60 institutions and organizations in 40 Member States, aimed at identifying the need for access to accelerator technologies and applications, including for education and training.

The Agency published a brochure entitled *Discover the World with Nuclear Physics* showing various applications of ion beams and neutrons for material modification and analysis. The brochure features case studies — ranging from the methods used to analyse water on Mars and optimize fuel cells to those used to monitor air pollution — demonstrating the usefulness of these techniques for scientific purposes and for everyday life.

## Nuclear Instrumentation

Over the year, the Agency’s Nuclear Science and Instrumentation Laboratory organized or contributed to a series of training workshops and courses held at the Agency’s facilities in Seibersdorf. About 100 participants from more than 30 Member States benefited from hands-on exercises using diverse instrumentation and detectors. Topics covered ranged from the use of radiotracers or radioisotope sealed source methodologies for industrial applications to radiological mapping with portable detection systems and nuclear analytical techniques employed for elemental analysis of various samples.

The laboratory also organized and hosted group fellowship training on analytical techniques and applications based on X ray fluorescence, providing training for five fellows from Brazil, Nigeria and Sri Lanka. It also commissioned a full-field X ray fluorescence spectrometer, used for non-destructive study of the spatial distribution of elements. The new equipment will be made available for training of fellows and young researchers.

In December, the Agency organized a Technical Meeting on Current Trends and Developments in Nuclear Instrumentation, where 11 experts from 11 Member States reviewed state of the art portable nuclear instrumentation for in situ environmental monitoring and discussed challenges for its effective utilization and maintenance.

In June, the Agency conducted an expert mission using backpack gamma spectrometers to measure radiation levels at the site of the Radiation and Technological Complex in

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*“[The Agency’s Nuclear Science and Instrumentation Laboratory] organized and hosted group fellowship training on analytical techniques and applications based on X ray fluorescence, providing training for five fellows”*

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FIG. 3. Testing of the equipment installed at the ion beam accelerator facility at the Bangladesh Atomic Energy Commission.

Tashkent prior to the site's release from regulatory control. In October, the Agency provided support for a national training exercise on monitoring radiological events using an unmanned aerial vehicle system for rapid environmental mapping at four sites in Brazil.

The Agency, on request, provided targeted scientific and technical support to small accelerator facilities in Bangladesh (Fig. 3), Lebanon and Thailand. This included setting up dedicated beamlines and instrumentation, assisting in maintenance, installing upgrades, troubleshooting of default equipment and training personnel.

The Agency coordinated two proficiency test campaigns for interested analytical laboratories to help Member States improve the quality of their analytical results. Forty-three laboratories from 33 Member States tested samples of urban dust loaded on air filters, and 41 laboratories from 29 Member States tested samples of marine sediment and animal tissue.

The Agency also developed a tool based on R Markdown — a plain text format used to create dynamic documents — to facilitate the interpretation of geographic information systems for radiological measurements and the production of maps. The software was distributed to 19 interested national organizations from 16 Member States.

## Nuclear Fusion

The 27th IAEA Fusion Energy Conference (FEC 2018) was held in Gandhinagar, India, in October. Over 700 experts from 39 Member States and 4 international organizations took part in discussions on key physics and technology issues, and on innovative concepts relevant to the use of nuclear fusion as a source of energy (Fig. 4).

The Agency issued a publication entitled *Integrated Approach to Safety Classification of Mechanical Components for Fusion Applications* (IAEA-TECDOC-1851), the first international reference document to comprehensively address this subject. The publication highlights the current state of the art assessment of safety classification of components for fusion applications.

The Agency's Eighth Technical Meeting on the Physics and Technology of Inertial Fusion Energy Targets and Chambers took place in Tashkent in March. Fifteen experts from 9 Member States took part, discussing technical solutions relevant to the design and



FIG. 4. The 27th IAEA FEC, a major event in the field of fusion, drew more than 700 participants and featured over 100 plenary talks and some 700 posters.

development of some key components of future inertial fusion reactors, including related safety considerations.

The Fifth IAEA Demonstration Fusion Power Plant Programme Workshop (DEMO) Programme Workshop, held in Daejeon, Republic of Korea, in May, assessed the present status of and prospects for progress in the use of magnet technology for magnetic confinement fusion, control of DEMO plasmas, and remote maintenance and plant logistics. The event included presentations on integrated assessment of liquid metals as plasma facing components on the first wall and divertor, on the status and progress of the Korean fusion demonstration reactor, and on the status and scientific objectives of the JT60-SA research tokamak in Japan. It was attended by 64 experts from 12 Member States and an international organization.

The First IAEA Workshop on Fusion Enterprises took place in June in Santa Fe, United States of America. During the workshop, 38 participants from 4 Member States analysed recent scientific and technical developments in this field, as well as the role of the private sector in the commercialization of future fusion energy systems.

During the 62nd regular session of the General Conference in September, the Agency organized a side event entitled 'Fusion Energy for Peace and Sustainable Development'. More than 100 delegates attended the event, which featured the film *Let There Be Light*, a documentary about the quest for fusion energy.

The Joint ICTP-IAEA College on Plasma Physics took place from 29 October to 9 November in Trieste, Italy. The college's 78 participants from 26 Member States focused on the study of collective phenomena of macroscopic systems in diverse settings such as classical and quantum domains, laboratories, space and cosmological systems.

## Support for the ICTP

The Agency continued to support the ICTP in 2018, conducting 12 joint events attended by about 240 participants. Through the Sandwich Training Educational Programme, the Agency supported 25 PhD students. Agency support for the ICTP enables scientists from developing Member States to enhance knowledge and exchange information in the fields of theoretical physics and applied sciences.