
Nuclear Science

Objective

To increase Member State capabilities in the development and application of nuclear science as a tool for their technological and economic development. To assist Member States in the management and effective utilization of research reactors.

Nuclear Data

The Agency worked with nuclear physics experts from national nuclear data evaluation projects to deliver high quality isotopic evaluations of actinides and structural materials to three major nuclear data libraries released in 2017: ENDF/B-VIII (United States of America), JEFF-3.3 (OECD/Nuclear Energy Agency) and TENDL-2017 (Europe). As part of the process, Agency and external experts performed integral validation with criticality benchmarks.

In November, the Agency held a Technical Meeting of the International Atomic and Molecular Code Centre Network on Molecular Dynamics Data of Collisional Cascades after Irradiation. At the meeting, 13 scientists from 11 Member States planned a database of computational simulations of neutron damage in materials. They also discussed various crowdsourcing initiatives that might be launched in connection with the database, including one on distributed computing.

A Technical Meeting on Nuclear Data Processing was held in Vienna in December, with 14 participants from 9 Member States. At the meeting, processing code developers discussed ways to ensure that reactor physics and fuel cycle software can continue to use well validated nuclear data libraries in the future. Participants also agreed to support an Agency activity, launched in 2017, to validate new codes under development in several Member States.

Research Reactors

Utilization and applications of research reactors

During the year, the Agency supported 28 neutron activation analysis laboratories from 23 Member States in validating their measurement results by providing proficiency testing through an interlaboratory comparison. Participants in a workshop held in November in cooperation with the Jožef Stefan Institute in Ljubljana, Slovenia, critically analysed the results of the proficiency testing to identify issues and discuss possible ways to improve results. In December, the Agency published *Proficiency Testing by Interlaboratory Comparison Performed in 2010–2015 for Neutron Activation Analysis and Other Analytical Techniques* (IAEA-TECDOC-1831), presenting the findings and lessons learned from tests performed

by 30 laboratories across the world. The Agency released its new on-line e-learning course on neutron activation analysis in October.

In August, the Agency conducted the third Training Workshop on Advanced Use of Neutron Imaging for Research and Applications, in cooperation with the Heinz Maier-Leibnitz Zentrum in Garching, Germany. During the workshop, 19 participants from 17 Member States delivered lectures and took part in practical exercises covering different neutron imaging methods, including applications in research and industry.

The Agency's Research Reactor Database (RRDB) continued to serve as the gateway to comprehensive technical information on over 770 research reactors built to date in 68 Member States, including information on their utilization. In 2017, information on 111 facilities was updated in the RRDB using input from Member States.

During the year, the Agency published *Strategic Planning for Research Reactors* (IAEA Nuclear Energy Series No. NG-T-3.16), providing guidance on and examples of how to prepare and implement strategic plans for existing and new research reactors. A new Agency brochure entitled *Research Reactors in Latin America and the Caribbean* provides a synopsis of the main research reactor activities in the region.

New research reactor projects, infrastructure development and capacity building

In 2017, the Agency carried out six fact-finding missions, provided guidance and supported the organization of national workshops in the following countries considering building research reactors: Azerbaijan, the Plurinational State of Bolivia (Fig. 1), Kenya, the Philippines, South Africa and Thailand. The Agency also worked with Nigeria on preparations for a new multipurpose research reactor. During the year, the Agency reviewed and provided recommendations to Nigeria on the feasibility study document and self-evaluation report on the status of its national nuclear infrastructure.

The Agency held two training workshops on various aspects of new research reactor projects at its Headquarters in Vienna during the year. In September, it hosted a Training



FIG. 1. One of several geological drills constructed as part of the site characterization for the new 200 kW research reactor in El Alto, Plurinational State of Bolivia.

Workshop on Assessment of the National Nuclear Infrastructure to Support a New Research Reactor Project, with 30 participants from 21 Member States. In October, it organized a Training Workshop on Preparation of a Feasibility Study for a New Research Reactor Project, with 30 participants from 24 Member States. The workshops provided practical information and a forum for sharing experience and lessons learned.

In 2017, the Agency's Internet Reactor Laboratory (IRL) project continued to provide nuclear engineering students and young specialists in Africa, Europe and Latin America with an opportunity to participate in live reactor experiments on-line. Two host facilities – Argentina's RA-6 research reactor and the French Alternative Energies and Atomic Energy Commission's ISIS reactor – provided live transmissions to participants in Belarus, Colombia, Cuba, Lithuania, Tunisia and the United Republic of Tanzania. In November, the Agency signed an agreement with Kyung Hee University in the Republic of Korea to initiate the broadcasting of the IRL in the Asia and the Pacific region in 2018. Morocco took steps to make its MA-R1 TRIGA research reactor at the National Centre for Nuclear Energy, Sciences and Technology the host research reactor for the IRL project in Africa.

The Agency provided support for the 13th Eastern European Research Reactor Initiative (EERRI) fellowship training course. The total number of professionals trained through EERRI grew to 105 in 2017.

The Agency organized the second Regional Research Reactor School, in cooperation with the Thailand Institute of Nuclear Technology in Thailand and the Dalat Nuclear Research Institute in Viet Nam. The School enabled 12 participants from 8 Member States to acquire on-site training experience at the two research reactors.

During the 61st regular session of the Agency's General Conference, the Belgian Nuclear Research Centre (SCK•CEN) and the United States Department of Energy's Idaho and Oak Ridge National Laboratories became IAEA-designated International Centres based on Research Reactors (ICERR). In December, the Agency established a network, ICERR-Net, to coordinate and optimize the services that ICERRs can offer to Member States.

Research reactor fuel cycle

The Agency hosted a Technical Meeting as part of the CRP entitled 'Benchmarks of Computational Tools against Experimental Data on Fuel Burnup and Material Activation for Utilization, Operation and Safety Analysis of Research Reactors', with 22 participants from 20 Member States. The purpose of the meeting was to enable Member States that are not involved in this CRP to contribute to the benchmarking exercise.

In November, the Agency, in cooperation with the International Centre for Theoretical Physics (ICTP), organized a joint workshop on 'Research Reactors for Development of Materials and Fuels for Innovative Nuclear Energy Systems'. The workshop provided 24 participants from 15 Member States with practical information and knowledge on the use of research reactors for R&D on the development and testing of materials and fuels for nuclear energy systems.

The Agency issued three publications related to the research reactor fuel cycle in 2017: *Use of Low Enriched Uranium Fuel in Accelerator Driven Subcritical Systems* (IAEA-TECDOC-1821), *Available Reprocessing and Recycling Services for Research Reactor Spent Nuclear Fuel* (IAEA Nuclear Energy Series No. NW-T-1.11) and *Research Reactors for the Development of Materials and Fuels for Innovative Nuclear Energy Systems* (IAEA Nuclear Energy Series No. NP-T-5.8).

The Agency continued to coordinate and provide technical support to the three year project to convert the Ghana Research Reactor-1 from high enriched uranium (HEU) to low enriched uranium (LEU) fuel. The project was successfully completed with the return in August of the irradiated HEU core to China (Fig. 2). Ghana is the first of the five countries operating a Chinese supplied miniature neutron source reactor outside of China to successfully convert and repatriate its irradiated HEU core.



FIG. 2. A three year project concluded in August with the successful repatriation to China of the HEU core of Ghana's miniature neutron source reactor.

The Agency's 11th Technical Meeting on Lessons Learned from High Enriched Uranium Take-back Programmes, held in Tbilisi, Georgia, in June, was attended by 83 participants from 18 Member States. The Technical Meeting on the Conversion of Miniature Neutron Source Reactors from HEU to LEU Fuel, held in Vienna in December, drew 25 participants from 7 Member States. Both meetings were aimed at sharing experience and lessons learned from the first conversion of a miniature neutron source reactor and the repatriation of its HEU fuel to China.

Research reactor operation and maintenance

In 2017, the Agency initiated several activities to help Member States address challenges related to ageing management and lifetime extension of research reactors, and optimization of their operational performance. In April, it launched a trial of a new database of properties of irradiated core structural materials for research reactors, containing 134 reports. The database resulted from the CRP entitled 'Establishment of a Material Properties Database for Irradiated Core Structural Components for Continued Safe Operation and Lifetime Extension of Ageing Research Reactors', which held its third and final Research Coordination Meeting in April.

In June, the Agency conducted a Pre-OMARR (Operation and Maintenance Assessment for Research Reactors) mission to the WWR-SM research reactor in Uzbekistan. The preparatory mission was used to finalize the plan for the main OMARR mission, which will assist the facility in preparing a plan for ageing management and continued operation with enhanced operational performance. In September, the Agency conducted a Pre-OMARR mission combined with in-service inspection to the RPI research reactor in Portugal. During the mission, the Agency provided a radiation resistant camera to examine the pool lining and core structural components, as well as technical support for detecting the source of a primary coolant leak.

In July, a Technical Meeting on Upgrades to Digital Instrumentation and Control Systems for Research Reactors was held in Vienna, with 29 participants from 21 Member States. Meeting participants exchanged knowledge and experience related to the installation of digital instrumentation and control systems in research reactors undergoing modernization. The Agency also published *On-line Monitoring of Instrumentation in Research Reactors*

(IAEA-TECDOC-1830), presenting fundamentals of on-line monitoring techniques such as data acquisition, qualification and analysis for improving research reactor performance, and providing the technical foundation and guidance for their use in research reactors.

In October, the Agency held a Technical Meeting on Research Reactor Ageing Management, Refurbishment and Modernization at its Headquarters in Vienna. The meeting's 34 participants from 29 Member States exchanged information on managing research reactor ageing, and shared experiences from ongoing projects aimed at modernizing and refurbishing research reactors. The Research Reactors Ageing Database was updated throughout the year with information provided by Member States.

Accelerator Applications

The Agency held the first Research Coordination Meeting of a new CRP entitled 'Accelerator Simulation and Theoretical Modelling of Radiation Effects – SMORE-II'. The results of this CRP will be used to develop recommendations for best practices in the use of ion beam research for simulating in-reactor damage to materials used for advanced reactor concepts and life extension of existing reactors.

In September, the Agency held a Technical Meeting on Modern Neutron Detection, attended by 42 experts in dosimetry and standards, neutron scattering, fusion, regulatory activities and safeguards, from 20 Member States. The participants discussed state-of-the-art technologies and the outlook for promising near term technologies for specific applications.

In June, the Agency held a Technical Meeting on Developing Strategies for Safe Analysis of Paintings and Paint Materials at the Rijksmuseum in Amsterdam, the Netherlands. The meeting was attended by 37 curators, conservation scientists, radiation specialists, physicists, chemists, and materials and accelerator scientists from 14 Member States. Participants discussed current practices in analysing cultural heritage items (Fig. 3) and monitoring radiation induced modifications in real time and over the long term. They also defined best practices for documenting the irradiation history of individual paintings.

The first meeting of a new CRP entitled 'Enhancing Nuclear Analytical Techniques to Meet the Needs of Forensic Science', held in November in Vienna, was attended by 19 experts from 14 Member States. The project is aimed at determining the ways nuclear



FIG. 3. A painting by Frans Hals, displayed at the Rijksmuseum in Amsterdam, the Netherlands, being analysed by macroscopic X ray fluorescence. (Photograph courtesy of the Rijksmuseum.)

analytical techniques can complement existing forensic methods in areas such as crime investigation, food safety and health related issues, cultural heritage artefacts, and environmental samples.

In 2017, researchers from six Member States carried out nine experiments using the Agency's X ray fluorescence beamline at the Elettra synchrotron in Trieste. The experiments focused on environmental science, fundamental X ray physics, cultural heritage and industrial applications. Seven of the nine tests were supported by the CRP entitled 'Experiments with Synchrotron Radiation for Modern Environmental and Industrial Applications'.

At a Technical Meeting on Trends in Analytical Applications of Synchrotron Based X Ray Spectrometry Techniques and Developments in the Supporting Instrumentation, held in October in Vienna, 27 specialists from 23 Member States discussed the current need of Member States, in particular of developing countries, for access to synchrotron facilities. Participants in a consultants meeting held in December in Vienna discussed the latest developments in accelerator instrumentation and expansion of the network of regional resource centres to foster advanced research in developing countries.

Nuclear Instrumentation

The Agency supported Member State efforts to improve the quality of results obtained using nuclear analytical techniques through proficiency testing, meetings and training activities. In 2017, 47 laboratories from 36 Member States took part in an Agency proficiency test for the determination of trace elements in samples of environmental origin. In June, the Agency held a Training Workshop on Quality Assurance for Nuclear Spectrometry, with 25 participants from 25 Member States. The workshop addressed topics such as validation of nuclear analytic techniques and methods, internal and external quality control activities, and the need for quality management implementation and laboratory accreditation.

Eleven participants from 11 African countries attended a Regional Training Course on Validation of X ray Emission Techniques for the Analysis of Air Particulate Matter, held at the Agency's Laboratories in Seibersdorf in May. The Agency provided group fellowship training on X ray fluorescence, focusing on qualitative and quantitative analysis of environmental samples, involving four participants from two Member States. A national training course on nuclear instrumentation held in South Africa was attended by 48 participants.

The Agency organized two consultants meetings to discuss actions required to extend the use of mobile gamma spectrometry teams in Member States. The first meeting addressed the training needs and modalities for training workshops on in situ radiological characterization and production of maps. The second discussed past and future actions of the INSITU working group, established to support environmental remediation projects. In December, an Agency mobile gamma spectrometry team conducted a field mission to Indonesia to support the characterization of sites associated with tin mining; the mission included visits to two mining locations and a reprocessing site.

Nuclear Fusion

The Agency's Fusion Portal, launched in 2016, became fully functional in 2017. The new portal provides information on all fusion related events organized by the Agency, including planned events, as well as publications and other outputs.

The Agency issued *Investigations of Materials under High Repetition and Intense Fusion Pulses* (IAEA-TECDOC-1829), presenting experimental results of plasma-surface interaction phenomena under the extreme conditions expected in a fusion reactor. The publication is

a compilation of studies investigating the mechanism of material damage during transient heat loads, and addresses the performance and adequacy of tungsten as a plasma-facing material for next step fusion devices such as ITER and fusion demonstration power plants.

The Agency launched two new CRPs in the area of nuclear fusion in 2017: 'Development of Compact Steady-State Fusion Neutron Sources' and 'Network of Small and Medium Size Magnetic Confinement Fusion Devices for Fusion Research'.

Throughout the year, the Agency hosted seven Technical Meetings, one workshop and a number of consultants meetings with members of the world's fusion community, involving 460 researchers from 43 Member States. It also cooperated in the organization of three international events: the 13th International Reflectometry Workshop, the Eighth International Conference on the Frontiers of Plasma Physics and Technology, and the Tenth International Conference on Inertial Fusion Sciences and Applications. Conference materials from the 26th IAEA Fusion Energy Conference were made available via the Agency's Fusion Portal.

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Support to the ICTP

In 2017, the Agency and the Abdus Salam International Centre for Theoretical Physics (ICTP) conducted 13 joint activities involving 681 participants from 100 Member States, of whom 345 were from developing Member States. Through the STEP (Sandwich Training Educational Programme) fellowship, the Agency supported 14 PhD students from developing countries, half of them women. Over the past 15 years, STEP fellowships have been awarded to 190 students from all over the world, enabling them to carry out research at advanced institutes. Through fellowships, the Agency funded the participation of 18 physicists in a two year Master of Advanced Studies in Medical Physics programme jointly conducted by the ICTP and the University of Trieste.