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IAEA activities in support of accelerator-based research and applications

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Summary. — Accelerator applications is one of the thematic areas, where the IAEA Physics Section supports IAEA Member States in strengthening their capabilities to adopt and benefit from the use of accelerators. A number of activities are being implemented by the IAEA Physics Section focusing on accelerator-based applications in multiple disciplines, facilitation of access to accelerator facilities, organization of meetings, coordination of joint research projects and capacity building in accelerator-based technologies and techniques. This communication reports on the currently implemented activities together with those planned for the near future.

1. – Introduction

Particle accelerators contribute to the welfare of modern society due to their unique analytical capabilities to investigate problems relevant to human health, environmental monitoring, water and air quality, development of advanced materials of high technological interest, forensics, cultural heritage, agriculture, and many other fields. At the same time, accelerators play a key role in capacity building, by providing not only education and training in high-tech sectors but also very specialized services. As such, they contribute to the increase of competitiveness of the local economies. In this context, activities in support of accelerator-based research and applications are being implemented by the Physics Section of the International Atomic Energy Agency (IAEA) [1].

The Physics Section is one of the four sections of the Division of Physical and Chemical Sciences (NAPC) that is part of the Department of Nuclear Sciences and Applications (NA) of IAEA. One of the primary goals of the Physics Section is to support IAEA Member States to establish frameworks for the efficient, sustainable and safe use of advanced nuclear technologies. The relevant activities fall into the IAEA's nuclear power, fuel cycle and nuclear science programme and cover four key areas, i.e., accelerator applications,

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research reactor utilization, controlled fusion research and nuclear instrumentation. In parallel, the Physics Section operates the Nuclear Science and Instrumentation Laboratory (NSIL) at Seibersdorf, located approximately 30 km south of Vienna. NSIL's primary mission is to assist IAEA Member States to establish, operate and maintain various nuclear instrumentation and spectrometry techniques in support of a wide range of applications.

2. – Current activities

The key activities in support of accelerator-based research and applications of the IAEA Physics Section focus on: a) Promoting the utilization of accelerators in support of applied research in almost all fields with high societal and economical impact, b) Enhancing utilization of existing accelerator infrastructures by enabling facility access for scientits from developing countries without such facilities, c) Assisting Member States in installing, operating and maintaining their accelerator facilities and associated instrumentation, and d) Assisting in carrying out feasibility and infrastructure assessment studies and establishing new accelerator facilities.

For the implementation of its key activities, the Physics Section utilizes also two cooperative agreements between the IAEA and the *Elettra* synchrotron facility [2], located in Trieste, Italy, and between the IAEA and the Ruder Bošković Institute (RBI) [3], Zagreb, Croatia. In the former case, synchrotron light users from IAEA Member States have access up to 40% of the beamtime at the X-ray fluorescence beamline, which hosts an ultra-high vacuum chamber, funded and operated in partnership with the IAEA. Similarily, RBI offers at least 4 weeks of beam time every year to scientists from IAEA Member States to perform experiments or for hands-on training organized by the IAEA Physics Section at the RBI's accelerator facilities. The activities in support of accelerator-based research and applications are implemented with following IAEA tools:

2˙1. *Coordinated Research Projects (CRPs).* – These are joint international projects bringing together scientists from research institutes in both developing and developed Member States to collaborate on research topics of common interest. Each CRP consists of a network of typically 10 to 15 research institutes that work in coordination for three to five years to acquire and disseminate new knowledge. Support to CRP member institutes is granted through research, technical and doctoral contracts. Cost-free research agreements are also established, primarily with institutions from developed countries. The IAEA acts as the sponsoring and coordinating body of the CRP and for this purpose an IAEA scientist is assigned to lead each CRP as the project officer. During the period of a CRP, research coordination meetings (RCMs) are organized for all CRP participants to present the progress of their work and schedule joint activities for the future. All CRP participants receive travel support to attend the RCMs. Common CRP outputs are the establishment of networks, databases, the development of testing devices or diagnostic tools, publications [4], as well as Masters and PhD theses.

The IAEA Physics Section is currently leading 13 CRPs in which almost 150 research institutions participate worldwide. Five CRPs cover accelerator-based applications with a total budget close to 2 million Euros. They focus on synchrotron radiation experiments for environmental and industrial applications [5], the use of nuclear analytical techniques for the needs of Forensic science [6], the utilization of ion beam techniques for tuning material properties for quantum technologies [7], the development of a new MeV-SIMS technique [8] for molecular concentration mappings with many perspective applications and on accelerator simulation and theoretical modelling of radiation effects [9].

2˙2. *Training Activities.* – These activities aim at enabling participants to acquire specific knowledge, either theoretical or practical or both, on a given subject of interest. The gained knowledge permits trainees in better utilizing the resources available to them in their countries. Training activities include training courses, training workshops and training seminars that are held either at the IAEA Headquarters or at NSIL in Seibersdorf. In certain instances, hands-on training courses are offered at partner institutions in Member States or on-site, at national laboratories. In addition, the Physics section organizes every year at least two training workshops and schools in coopeartion with the International Centre for Theoretical Physics (ICTP) [10] in Trieste, Italy.

In 2018, two training workshops were organized in the field of accelerator-based applications and technologies: A training workshop on *Ion Beam Analysis Techniques* [11] with hands-on-training, held in April 2018 at RBI [3] in Zagreb, Croatia, and a Joint ICTP-IAEA Advanced Training School entitled *Ion Beam Driven Materials Engineering: Accelerators for a New Technology Era* [12], held in October 2018 at the ICTP.

2˙3. *Technical Meetings.* – These are technical events with up to 30-40 participants with one-week long duration, organized in Vienna or in IAEA Member States, with the aim to enhance interaction among experts, share knowledge and expertise, establish scientific collaborations and create topical networks. Apart from proceedings, these meetings often result in initiation of Technical Documents (TECDOCs) like, e.g., that of Ref. [13], which are published by IAEA to serve as reference publications for scientists all over the world. Invitations to attend a Technical Meeting are sent to all Member States and to selected organizations requesting designation of participants and/or submission of scientific contributions, depending on the nature of the meeting.

The Physics section organizes annualy around five Technical Meetings, which are attended by almost 200 scientists from more than 50 Member States. One of the Technical Meetings held in 2018 in the area of accelerator applications in multiple disciplines was on *Advanced methodologies for the analysis of materials in fusion energy applications using ion beam accelerators*. It was attended by 30 experts from 15 IAEA Member States. The conclusions of the meeting will become available to the international scientific community with an upcoming publication in a peer-reviewed journal

2˙4. *Consultancy Meetings.* – These are meetings of five to ten experts who are invited by the IAEA with the purpose to provide specialized advice and recomendations on particular scientific or other aspects of relevance for the IAEA's programmes and activities. Consultancy meetings are often held to prepare the scope of a CRP before its launch or a Technical Meeting before its announcement or with the aim to review a Technical Document before its publication. In 2018, several consultancy meetings were held at the IAEA. In March 2018, a special Technical Meeting entitled *Facilitating Experiments with Ion Beam Accelerators* was organized with the aim to prepare the modalities necessary to run a new CRP.

In July 2018, another consultancy meeting was held on *Novel multidisciplinary applications with unstable ion beams and complementary techniques*. The meeting covered topics such as the status of operation and program implementation of existing Radioactive Ion Beam (RIB) facilities across the world, the type of RIB-based research activities and their multi-disciplinary features and applications, and the potential for innovation at RIB facilities as well as the needs for training on RIB technologies. In view of the continuously increasing number of applications in this field, the meeting participants reccommended the organization of a Technical Meeting.

2˙5. *Support of events in cooperation.* – The IAEA supports international schools, workshops or conferences announced as "organized in cooperation with the IAEA". Such events are receiving financial supported in the form of grants for scientists from IAEA developing Member States to enable them to participate in the event. A recent international conference supported as an event organized in cooperation with the IAEA was the 13th International Topical Meeting on the Applications of Accelerators (AccApp'17) [14] held in 2017 at Quebec, Canada.

2˙6. *Support to Technical Cooperation projects.* – The Technical Cooperation (TC) programme [15] is the IAEA′s primary mechanism for transferring nuclear technology to Member States, helping them to address key development priorities in many areas of societal importance and economical growth. It is implemented primarly in the form of projects, which provide support through capacity building, knowledge-sharing and partnership-building as well as support for networking and procurement. In the field of accelerator applications, the Physics Section provides technical support to 10 national TC projects and 11 regional or interregional TC projects, representing more than 50 Member States.

As example we refer to a current TC project receiving technical support by the Physics Section that focusses on the utilization of Tandem Accelerator Facility of the Bangladesh Atomic Energy Commission (BAEC) that was recently installed for research, development, and industrial services in various developmental areas, such as food and agriculture, health, industry and environment. Through this project scientific and technical staff receive training on vacuum techniques, in maintaining different complex parts of the local accelerator and its ion sources, as well as training on ion beam analysis (IBA) techniques. For this purpose scientific staff of the Physics Section visit BAEC and give the necessary training, or assist in procurement through the TC programme of IAEA.

Worth noting is also the extensive support provided by IAEA within an interregional TC project to train staff of the SESAME Synchrotron [16], the Middle East's first major international research centre, to safely commission and run the facility. This has included the training of 66 technical and scientific fellows in beamline technologies, and over 30 expert missions to SESAME to help build capacity in the installation and testing of equipment. IAEA also facilitated the networking of SESAME staff with experts from other synchrotron facilities in Europe, the United States and Japan.

2˙7. *The Accelerator Knowledge Portal (AKP).* – IAEA's "Accelerator Knowledge Portal" (AKP) [17] is maintained and managed by the Physics Section since its first launch in 2014. AKP offers a comprehensive database of accelerators worlwide. As of today, 217 electrostatic accelerator facilities, 64 synchrotron light sources and 10 spallation neutron sources are listed. AKP is continuously updated based on the input from the Member States. The portal has several networking and communication features with the objective to provide information to accelerator users and policy makers. It provides also up-to-date information on relevant conferences, workshops and schools; technical reports, journal articles and books as well as links to relevant software packages and databases.

3. – Planned activities and outlook

In the short-term future, the Physics Section will continue with the organization of technical and consultancy meetings, the implementation of the active CRPs as well as the initiation of new ones, the cooperation with *Elettra* and RBI, and the provision

of guidance for accelerator facilities for long-term sustainable operation. Besides the RCMs of the currently running CRPs, following activities are planned for the following 12 months:

- Technical Meetings on: a) Novel Multidisciplinary Applications with Unstable Ion Beams and Complementary Techniques; b) Data Acquisition Systems Used for Nuclear Instrumentation at Particle Accelerator Facilities; c) Non-spallation Accelerator-based Production of Neutrons; d) Long-term Sustainability of Accelerator Facilities.

- Training workshops and schools on: a) Accelerator-based Analytical Techniques for Forensic Science (Joint ICTP-IAEA workshop [19]); b) Safe Analysis of Cultural Heritage Materials with Ion and X-ray Beams; c) Electrostatic Accelerator Technologies, Basic Instruments and Analytical Techniques (Joint ICTP-IAEA workshop [20]); d) Hands-on Operation and Maintenance of Electrostatic Accelerators.

- Consultancy meettings on: a) Advances in laser-driven neutron and X-ray sources; b) Socioeconomic effects of accelerator technologies in Developing Countries; c) Status and Advances of Bio-medical Imaging with Ion Beams, X-rays and Other Complementary Techniques; d) Recent developments in ion-sources for ion-beam accelerators; e) Developments in Plant Breeding Using Ion Beam Irradiations.

Of special interest for the worldwide accelerator user's community is the recently launched CRP entitled "Facilitating Experiments with Ion Beam Accelerators" [18]. The aim of this CRP is to facilitate scientists without access to accelerator facilities to conduct experiments using accelerator-based ion-beam analytical techniques. This will be accomplished through the identification and selection of participating institutions ("hosts"), which will provide access to ion beam laboratories and expertise in ion beam analytical techniques. The scientists previously without access ("guests") will thus derive benefits from access to related analytical and irradiation techniques, as well as build the necessary capacity if such facilities were planned in their countries in the future. The CRP aims also at further promoting new collaborations and networking among researchers, accelerator specialists and other stakeholders interested in the accelerator-based analytical techniques.

Looking forward, the IAEA Physics Section is making efforts towards establishment of an MeV ion beam accelerator at Seibersdorf. For this purpose, a comprehensive feasibility study has been performed to assess whether and how the acquisition and operation of an accelerator in Seibersdorf could match the NSIL's mission and existing programme for capacity building as well as the provision of services across many fields of relevance to the IAEA and its Member States. The feasibility study, included, among others, a stakeholder analysis and users' needs. The analysis of IAEA Member States' current needs was conducted based on the evaluation of a comprehensive questionnaire. More than 60 replies from almost 40 Member States were received. They showed that most commonly demanded topics include:

- Training in: a) accelerator technology, such as ion sources and vacuum systems; b) end stations, such as design and assembly, radiation detectors, control systems and nuclear electronics; c) Ion Beam Analysis (IBA) techniques.

- Services relevant to: a) IBA for bulk analysis of air pollution, environmental, trace elements in reference materials and b) Nuclear microprobe applications, such as micro-PIXE, RBS, NRA, particulate reference materials.

- Applied research using: a) IBA for homogeneous bulk analysis of air quality, archaeological samples, and minerals and b) 2D and 3D imaging and spatially resolved analysis using a microprobe.

4. – Summary

In line with the mission of the IAEA, the Physics Section supports Member States in strengthening their capabilities to adopt and benefit from the use of accelerators. For this purpose, various activities are implemented using well-established implementation tools and modalities of the IAEA which assist scientists from Member States to:

- Recommend new fields of research and development with increased potential for applications (Consultancy Meetings)
- Exchange new ideas focusing on promising applications of societal impact and innovative solutions to problems of modern society (Technical Meetings)
- Establish networks working in collaboration (Collaborative Research Projects)
- Receive training on advanced nuclear technologies and nuclear-oriented research (Training Workshops and Schools)
- Organize conferences, workshops, and schools in cooperation with the IAEA.

In the short-term future, the IAEA Physics Section will continue implementing all aforementioned activities in support of accelerator-based research and applications. In the longer run, additional efforts will be made towards establishment of an MeV ion beam accelerator at Seibersdorf.

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