Review Paper

Panel and Round Table Discussion on Particle Accelerators in Analytical and Educational Applications

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Abstract. The International Atomic Energy Agency (IAEA) has been active in supporting initiatives to establish, maintain and utilize accelerator installations around the world. It has played an important role in the training of scientists as well as facilitating international networking. Review of current and future applications of accelerators in an ever changing and global technological society of integrated science, technology and innovation is useful to broaden international understanding of accelerator technology and utilization.

1. Introduction

During the International Topical Meeting on Nuclear Research Applications and Utilization of Accelerators organized by the International Atomic Energy Agency and the American Nuclear Society, held in Vienna, Austria from 4 to 8 May 2009, a Satellite Meeting on Particle Accelerators in Analytical and Educational Applications followed by a Panel and Round Table Discussion, was organized with the main purpose to discuss, in the context of an evolving information and knowledge driving society, the role of small particle accelerators in science and education with the participation of international experts. The focus of the Satellite Meeting was to review and discuss a range of utilization programmes of small accelerators in physical and chemical analytical applications as well as an invaluable tool for research and high level university education and training of young scientists.

The International Atomic Energy Agency (IAEA) has been active in supporting initiatives to establish, maintain and utilize accelerator installations around the world. It has played an important role in the training of scientists as well as facilitating international networking. Review of current and future applications of accelerators in an ever changing and global technological society of integrated science, technology and innovation is useful to broaden international understanding of accelerator technology and utilization.

The IAEA has in the past few years organized or co-organized several scientific meetings on the subject of accelerators. The most recent one in 2007, in cooperation with the American Nuclear Society the AccApp07 took place in Pocatello, Idaho, USA. In this opportunity, a Round Table Discussion was organized to review some limited aspects as well as current and future applications of accelerators and to provide insight and inputs for the Secretariat of the IAEA to plan future activities in the field. In this opportunity, the focus of the Panel was to discuss the developments in accelerator technology methods of materials testing such as probing for cracks in bridges, medical applications such as manufacturing cyclotron-produced pharmaceuticals or enhancing the imaging of tumors and bacterial sterilization with ionizing radiation, including homeland security issues such as probing for buried explosives and searching for nuclear weapons concealed in cargo containers. Initiatives in employing accelerators for producing energy in nuclear power plants were also discussed.

Particle Accelerators have become important tools both, for basic and applied research for the generation of fresh knowledge as well as for applications in a large variety of fields including advanced training and education for new generation of scientists. Industrialized and developing nations have benefited from this technology to advance their knowledge based technology not only of the industry, but also in material sciences and analytical applications in a large variety of substrates. The applications in medicine are well known and widely used.

Although accelerator technology is already well advanced, it continues to be developed with the aim of improving performance, lowering the cost and, producing specialized design for specific purposes. For instance, small accelerators are ideal tools for advanced basic and applied research in universities that covers a wide range of practical analytical applications in environmental sciences, exploration and exploitation of natural resources and materials of cultural and historical value, through techniques such as PIXE, PIGE and micro beams, in addition to playing a fundamental role in education and training of scientists. A large number and variety of accelerators ranging from small linear proton accelerators of a few MeVs, and single or dual particle cyclotron accelerators have been installed in the laboratories of many developing nations.

With the experience gained thus far, scientists managing these machines are today eager to increase the utilization time by expanding the spectrum of relevant analytical applications to a truly multidisciplinary one, and making efforts to establish collaborative research with other Centres around the world. In these regard, scientist from these regions see the IAEA as the central or focal point to nurture and facilitate such international collaboration. International scientific meetings of the type organized by the Agency can proactively provide the right atmosphere where scientists from advanced and developing nations can meet. One has to remember of the few opportunities that scientists from developing countries have to meet with other scientists and thus, interact and exchange fruitful experience.

The main general topics discussed at the Satellite Meeting included general analytical applications of accelerators, micro beams in physical and chemical analytical applications, accelerators as an advanced tool for education and training and possibilities for networking for collaborative research and training. There were five Contributed oral presentations and one Invited presentation distributed in two consecutive sessions, the first chaired by S. Fazinic from Croatia, and the second by H. Vera Ruiz from Bolivia. The full papers of these presentations are included in other part of the Proceedings.

The Panel and Round Table Discussion were chaired by H. Vera Ruiz from Bolivia. This session was attended by some 30 scientists from more than 10 countries. Scientists from Germany, USA, Croatia and Brazil were invited to be Members of the Panel and make opening remarks to which, a lively discussion followed. In what follows, an account will be given of the topics discussed in the Panel and Round Table Discussion.

2. Ion-Beam Analysis for Cultural Research

M. Rossbach, Forschungszentrum, Juelich, Germany

The interesting applications of accelerators in the investigation of art objects as part of the studies of the cultural heritage of nations and cultures was introduced and discussed by Matthias Rossbach from the Research Centre of Jülich in Germany. Ion beam facilities are available for analytical purposes in many research establishments world wide. A variety of analytical techniques based on interaction of charged particles with matter such as proton induced x-ray emission (PIXE), proton induced gamma ray emission (PIGE) or Rutherford backscattering (RBS) are routinely applied for surface elemental analysis of materials from industry, biology or the environment. Research applications particularly appealing to students belong to the field of forensics and cultural heritage. If existing ion beam facilities can be modified for ‘in-air’ irradiation, valuable materials such as large archaeological findings, paintings, or ancient metal objects that should not be deteriorated during the analytical process can be easily investigated. Compositional information from IBA investigations can help art historians, curators, restorers or archaeologists in a number of ways, e.g., determining authenticity, provenance, production process or simply which type of material was used to guide in the restoration process.

However, close cooperation of the analyst with experts of the mentioned disciplines is essential to generate meaningful results. Particularly, newcomers in the field are advised to network with more experienced laboratories e.g. in France or Italy that offer also small grants to students and useful assistance in instrumentation. As a side effect, scientific investigations of ancient objects can have substantial socio-economic impact in developing countries with a rich cultural heritage by stimulating commerce, tourism and strengthening national consciousness. In that respect, assisting laboratories in developing countries to establish IBA facilities through Agency's technical cooperation programmes can have high visibility and political significance.

In addition ion-beam mass spectrometry is currently the most sensitive method for age determination of organic material through C-14 analysis. Here, the 'bomb pulse technique' is covering the last 50 years since the above ground nuclear tests during the 1950^{th} and '60^{th} and the Libby's method covers some 100 to 50.000 years from now. Very exciting applications from aging of ancient human remains to determining the age of the ice man can be cited to stimulate the young generation to take up studies using accelerators and ion beam technology.

The Panellist also emphasized the concept that finding practical and interesting applications of accelerators may attract the involvement of young scientists to the nuclear field and, that networking with other accelerators centres would provide the synergies for a more effective applied multidisciplinary research. He also drew the attention to an upcoming IAEA publication resulting from a Coordinated Research Programme on the use of nuclear techniques for the study of the culture heritage of nations. A number of scientists from advanced and developing countries have participated in the CRP.

3. Some Notes on Small Accelerators for Education

R. Lanza, Massachusetts Institute of Technology, USA

The use of small accelerators for educational purposes was discussed. Some of the points made by the Panellist Richard Lanza of the MIT, USA, were to consider carefully the goals of such projects. The primary goal should be to train students in accelerator science and technology, not to establish a research program, although this may follow later. Some other considerations are to consider small self-contained experiments which can then be used to teach research oriented students techniques for larger accelerator labs and to emphasise educating young people using 'hands on' instruction . This may have two other implications. One is to explore novel applications and the other to train non-specialists in the use of accelerator techniques. This might be a way of extending the interest in accelerators to specialists in other areas such as biology, materials science, and chemistry who may not be familiar with the potential of small accelerators which are readily accessible to university researchers.

Some possibilities are DD and DT generators. These are well developed, commercially available sources of neutrons which are generally very compact. Other machines include electrostatic machines, cyclotrons or electron linear accelerators. As part of a number of programs in applications of accelerator technology, there have been new developments in these areas which have made such machines far more compact and reliable than in the past and as a result, perhaps more appropriate for student operation.

There are also a fair number of machines which may have been "retired" from research facilities and which are often available" free". Here one should exercise some caution.; free machines are often very old machines custom built by a research group in a university and may be poorly documented and use components which are no longer available. One should distinguish carefully the difference between price (zero) and true cost which includes transport, installation and the great amount of time which may be required to get such machines into operation. Lanza's sort of recommendation is to be prepared to spend either considerable time or money, perhaps both and that getting an old machine into operation can also be thought of as part of an educational process, so it is not all a negative.

Similar to other Panellists as well as from comments of the attending audience, is that small accelerators are ideal tools for training of scientists in science and technology, including the extensive spectrum of nuclear sciences and applications. The utilization of these machines can provide the proper environment for multidisciplinary research encompassing such a variety of subject ranging from biology to environmental and material sciences.

4. Small Accelerators for Undergraduate Research and Education

G.F. Peaslee, Chemistry Department, Hope College, Holland, Michigan, USA

M. Peaslee from the Chemistry Department of Hope University, Michigan, USA, presented his views and discussed the role of small accelerators in undergraduate research and education in science and technology as the central and crucial role of universities in a modern society with a view of attracting students to sciences. Peaslee pointed out that there has been a significant amount of change in our field recently, and how we adapt to such change will be a direct measure of how well small accelerator-based science survives, or even succeeds in the future. These changes have taken place in our student demographics – they come from different backgrounds from us, they have different interests and abilities that we had as students, and they are motivated differently by younger scientific disciplines, compared to the well-established nuclear science disciplines from which accelerator-based science has grown. There has also been a remarkable change in technology over the past decade, especially with modern small accelerators that are much more robust and user-friendly than their counterparts from a few years earlier. In addition, there are tremendous advances in communication technology that allows much more regular exchange of information between remote locations via video conferencing and even remote operation/interaction of accelerator facilities. There has even been change, as there always has been, in the science we study. The disciplines today have their boundaries blurring rapidly with the increased importance of interdisciplinary work, and the increased emphasis of learning more broadly than just a single discipline, even as an undergraduate.

The Panellist suggested some ways in which we can respond to these challenges of the changing times. In terms of our changing student populations, we clearly need to change our educational approach. Teaching lectures and standard laboratories is not longer sufficient to attract a continual flow of students into our discipline. Engaging students in real research endeavours will do it, and they can be started very early in their scientific career with wonderful success, both in the science produced and in the educational outcomes for the students. Secondly, let us take advantage of the advances in technology to not only utilize modern small accelerator facilities with our students, but to increase the communication between this increasingly isolated communities of experts. Not only can we attract outside users and students from other disciplines into our science by remote operation of accelerators and detector technology, but we can use cheap and effective videoconferencing technology over the web to connect labs from around the world that pursue similar types of ion beam analysis work. There is no need to re-invent the wheel at each of more than 50 accelerator facilities around the world, especially in terms of student recruitment and training, but development of a truly global shared database of expertise and methods would advance our field tremendously – and the technical tools to do this now exist. Not only methodology could be shared, but there are many examples of scientific research projects that could be expanded to become multi-institution projects. The Panellist cited, for example, his own work into forensic analysis of sand grains to determine provenance of the minerals within them. Clearly every small accelerator facility in the world has access to sand and soils, and this could easily become a joint project to develop a worldwide database of information that could be used in forensic geology readily. There are likely dozens of such projects that could be contemplated, and even funded eventually.

Lastly, he concluded by saying that we need to make our future educational efforts with small accelerators “science-driven”, rather than developing just pedagogical experiments for students. There is ample evidence from assessment in other fields that hands-on mentored research has a very positive and lasting impression on young students, and that research with small accelerators is no different. Exposure to sophisticated instrumentation (with guidance) as well as the combination of exciting interdisciplinary projects for which ion beam analysis is well known, will undoubtedly attract students to our field – we just need to facilitate this with our existing instrumentation and with new instrumentation that is now becoming available. We should also, at some point, asses the impact of this educational approach for our particular discipline, compared with some of the other disciplinary assessment studies. Finally, Paeslee asserts that we will find that stimulation of student interest and retention in the Science, Technology, Engineering and Mathematics fields will be greatly enhanced.

5. Micro Beams in Physical and Chemical Analytical applications.

S. Fazenic, Rudjer Boskovic Institute, Zagreb, Croatia

The topic of micro beam analysis was discussed by S. Fazenic from the Rudjer Boskovic Institute, Croatia emphasizing the role of accelerators in academic research as well as the need to standardize the terminology to facilitate communication and a common understanding. Small accelerators are ideal tools for advanced basic and applied research in universities that covers a wide range of practical analytical applications in environmental sciences, exploration and exploitation of natural resources and materials of cultural and historical value, through techniques such as PIXE, PIGE and micro beams, in addition to playing a fundamental role in education and training of scientists. The term 'micro beam' is related to the term 'micro probe' through one of many possible definitions: 'A micro probe is an instrument that applies a stable and well-focused (micro) beam of charged particles (electrons or ions) to a sample' (Wikipedia).

In this sense, there are several classes of instruments and techniques which employ well-focused beams of charged particles, starting from small (almost table-top) to large instruments, like:

- Focused Ion Beam (FIB) instruments,
- Electron micro probes (like for example scanning electron microscope),
- Ion micro probes.

There are two distinct classes of ion micro probe facilities:

- Those employing SIMS (Secondary Ion Mass Spectrometry),
- Nuclear micro probe (nuclear microscope).

Another micro beams associated with accelerators could be X-ray micro beams produced by very large electron synchrotrons. The web site lightsources.org lists 69 synchrotron light sources based on storage rings and free-electron lasers (operational, planned or in construction), and some of these can provide micro beams. The panellist gave a brief overview of the scope of these techniques.

Focused Ion Beams (FIB)

Usually gallium ions are accelerated to 5-50 keV and focused onto the sample by electrostatic lenses. It is used for site-specific analysis, deposition and ablation of materials, as micro machining tool (sputtering), ion beam induced deposition of materials, for modifying existing semiconductor device, or for sample preparation for TEM.

Variation: helium ion microscope

This is quite new technique, only one commercial instrument so far. Helium ions with 25-30 keV energy are used for surface imaging and material surface composition analysis by Rutherford Backscattering (RBS). The spatial resolution is less than 0.9 nm. It produces high quality images, comparable or better than SEM.

Electron micro probes

Probably the most widely used of all mentioned here. Used for imaging, elemental composition, chemical structure, etc. Many variations, from smaller and less complex to larger and very complex devices and available analytical techniques:

- Scanning Electron Microscope (SEM)
- Transmission Electron Microscope (TEM)
- High-Resolution TEM
- Reflection Electron Microscope (REM)
- Scanning Transmission Electron Microscope (STEM).

Ion micro probe employing SIMS

Used for chemical analysis of small volumes of materials. Surface of a sample is bombarded under vacuum with a finely focused beam of primary ions (Cs+, O+, O-, Ar+), and secondary ions from the sample are analysed by mass spectrometer. It can be used to perform point analysis (composition in a point, spot size 1 to 25 μm), depth profiling (scanning of primary ions, surface layers slowly eroded) or for imaging (elements/isotopes distribution, spatial resolution about 1 μmeter).

Although it is usually used as low energy SIMS (keV energy range), there are variations where MeV electrostatic accelerators are used (high-energy SIMS):

- standard SIMS used as injector, secondary ions analysed by acceleration to the MeV energies (sort of AMS: SIMS-AMS)
- High energy primary heavy ion beam, analysis of molecular ions from the sample.

Nuclear Microprobes

Ion beams with typical energies of several MeV are focused to sub-micrometer dimensions and scanned over a sample. It can be used for material characterization by Ion Beam Analytical (IBA) methods and for Ion Beam Modification of Materials. Typically are installed at MeV electrostatic accelerators, either single stage or tandems. As in the case of high energy SIMS installations, these are relatively large installations with quite limited number of installations.

Since not many laboratories may have the possibilities to have in place all of these techniques and instruments, particularly laboratories from small non-research oriented universities and laboratories in the developing world, it became clear during the discussions that it would be worthy to explore the feasibility of 'remote access' to the machines and experimental facilities by scientists under protocols and collaborative schemes to be defined. This interesting concept is not a new one, but it needs still to be discussed from several angles, including costs and benefits. In this context, it was pointed out that the IAEA may like to look into this matter with a view of fostering multidisciplinary and multi-centre collaborative research and stimulating the formation of small accelerator networks.

6. Why Brazilian Graduate Courses do not meet the Needs of the Market for Accelerators

A.C.V.S. Santana, Radiopharmaceutical Solutions, Sao Paulo, Brazil

The Panellist Ms. Santana addressed the issue of the lack of trained man power in the Brazilian society and its causes. Interesting changes has happened recently in the Brazilian legislation that opened the possibility for the private initiative to produce short-lived radionuclides with cyclotron for medical use. The import and production of radioactive material was the monopoly of the State, including radionuclides for medicine like ^{99}Mo-^{99m}Tc generators. This has changed due to a much welcome amendment in the National Constitution. Taken advantage of this situation, up to now, three Brazilian private organizations have started ambitious project for the installation and operation of three accelerators. Many more are foreseeing to be installed in the near future as the PET (Positron Emission Tomography) techniques become more widespread and affordable for the Brazilian citizens, not only in the large cities like Rio de Janeiro and Sao Paolo, but also in other cities in the interior of the country.

However, the management of these installations has encountered difficulties in finding and hiring qualified professionals in the field, thus underscoring the current lack of nuclear scientists and engineers in the Brazilian market. It is perceived that several are the reasons for this situation, being the main ones the lack of specialized programmes and undergraduate and graduate courses in the universities and an unjustified fear or culture of risk perception of the use of nuclear technologies by the young generation. Only education and the correct information to be provided to the public will change this attitude. The government agencies as well as the universities may have to take a more pro-active role in this regard.

It is suggested that the Government through the national agencies should take a more pro-active initiative for man power development of scientists in the nuclear field, perhaps in collaboration with the IAEA. The industry on the other hand, should also start developing its own expertise as well as encouraging the national nuclear centres in the country to strengthen their training programmes to secure a more efficient use of the accelerators installed and to be installed in the country.

The Panellist also mentioned that the many well trained nuclear professional has reached a retirement age and that there is an urgent need to prepare a new generation of nuclear professionals.

This issue underscored the dramatic situation of the lack of sufficiently trained man power in nuclear sciences and engineering not only in Brazil but in many develop and developing countries through out the world. The Panellist believes that both, the academia as well as the industry, have to play a more active role in the training of young professionals in order to sustain vigorous and healthy nuclear programmes, including the utilization of accelerators in medicine.

7. Conclusions

From the presentation of the Panellists and from the discussions that ensued with the audience, the following can be concluded very broadly:

1. Small particle accelerators are ideal tools for basic and applied research in universities as well as for advance training of undergraduate and graduate students covering a wide range of practical analytical applications in environmental and material sciences, exploration and exploitation of natural resources, in biology and medicine as well in the study of materials of cultural and historical value.

2. Accelerators, in various forms, have been operating in many developed and developing countries for several years and considerable experience in their operation and maintenance has been acquired. Most of these accelerator facilities are located in universities or research institutes and are therefore government supported facilities. Accelerators located at research institutions and universities have become an essential tool for research, training and education.

3. Ion beam techniques are today well developed and are suitable for the utilization of non nuclear specialists such as biologists or geologists and others, thereby providing the opportunity for interdisciplinary research, either at a national level or even on a regional and international level.

4. With more than 50 accelerator facilities around the world, there is an opportunity to develop a truly global share database of expertise and methods that would advance the field tremendously and contribute to increase the communication of an increasingly isolate community of accelerator experts. The technical tools already exist in the form of videoconferencing over the web. ASDA (Accelerators for Sustainable Development in Africa) is one outstanding example. Remote access to experimental facilities may be another interesting aspect to be explored and exploited in the future.

5. The experience has shown that future educational efforts with small accelerators have to be 'science-driven' including hands-on mentored research rather than just the classical pedagogical experiments. Unlike common believe, the tutored exposure to sophisticate instrumentation to young undergraduates is possible and desirable. Undergraduate students with proper guidance can produce first quality papers publishable in referee journals.

6. It is acknowledge that there is a shortage of well trained scientists and engineers in the nuclear field and its applications. This shortage is more pronounced in the developing nations as they are increasingly interested in the installation of accelerators, particularly of cyclotrons for the production of radionuclides for the practice of PET. Government nuclear agencies, universities and the nuclear industry itself may have to play a more pro-active role to address the matter.