

RELEVANCE OF ACCELERATOR/STORAGE RING TECHNOLOGICAL DEVELOPMENTS
TO U.S.A. SCIENCE AND TECHNOLOGY--PAST, PRESENT, AND FUTURE

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The invention and development of particle accelerators and the associated technology has had a profound impact upon the progress which has been achieved in U.S. science and technology. It has been a joint effort of those who build accelerators and those who use them, each playing a vital role. The contributions from the past by the accelerator community are continuing now, and there is every reason to believe that they will continue in the future.

Introduction

The purpose of this paper is to discuss the "Relevance of Accelerator/Storage Ring Technological Developments to U.S.A. Science and Technology." When I first started to think about this paper, it seemed a simple task. What one would do is discuss the many applications of particle accelerators and storage rings in science, medicine, and industry; project some of the newer applications of particle accelerators which are being discussed and studied, and discuss some of the future impacts which will result from new developments in accelerator science and technology.

There are two difficulties with such a presentation. First, such a description of the impact of accelerator technological developments on U.S. science and technology would grossly understate the real situation. It speaks of spinoffs and side benefits, and doesn't really convey the central role which accelerators have had and continue to have in the entire development of our science and technology.

The second difficulty is that it concentrates upon the impacts of accelerator technological developments in the past and the present and does not give adequate attention to the future. However when I look into the future I see real challenges which the accelerator community must consider if it is to optimize its future contributions to science and technology. In the discussion below I wish to discuss these past and present contributions, and to discuss some of the challenges I see ahead.

Past Contributions of Accelerator Development

The development of particle accelerators has played a central role in the development of modern science and technology. The situation is somewhat analogous to that portrayed by Baron Stig Romel, President of the Nobel Foundation, in a recent address honoring the winners of the annual Westinghouse science talent search. Baron Stig Romel pointed out that the invention by Alfred Nobel of Dynamite did not, as predicted, influence the course of warfare. Dynamite is not in general used in warfare. However the invention of dynamite did have major impact. It made possible the transcontinental railroad, the Panama Canal, and tunnels through the Alps. Without a relatively safe explosive these projects would have been nearly impossible.

In a similar vein, let us ask what would be the state of U.S. science and technology if particle accelerators had never been invented. Here we must decide where to start. For example, the early x-ray machines are in fact particle accelerators, and have had enormous impact in diagnostic medicine, nonde-

structive testing, therapy, etc. However so as not to appear to claim too much, let me start with the first electrostatic accelerators with sufficient energy to produce nuclear disintegrations. This was achieved by Cockroft and Walton in 1932 when they were able for the first time to produce a nuclear reaction by means of artificially accelerated positive ions. We will suddenly declare these early accelerators and all their decedents past, present, and future to not exist. What would be the consequences?

The most obvious consequence clearly would be that the very large body of nuclear data and understanding of nuclear physics required to produce research reactors, nuclear power plants, and nuclear weapons would not exist. Our understanding of the nucleus would be very meager indeed. While artificial radioactivity produced by bombardment of light elements with α -particles from natural radioactive elements was discovered in 1919, and neutrons were discovered in 1932 by α -particle bombardment of light elements, our knowledge of radioactivity would be very small. Mesons --if in some way we had developed the means to detect them--would be a strange phenomena observed in the cosmic rays. In short, nuclear physics and elementary particle physics with their elegant development of instrumentation and theoretical methods and their profound contributions to our understanding of the constituents of matter and energy and of the fundamental forces, would not exist as we know them today.

The effects would be apparent also in other areas of science and technology. Nuclear medicine and the widespread use of accelerators in cancer therapy would not exist. Electron microscopes and the many uses of neutrons and accelerators in materials research would not exist. The idea of fusion power would not have occurred. The many uses of nuclear techniques in the analytical laboratory would not exist. There would be no radiation processing industry, which now is having ever increasing impact in developing new and improved products and in providing a host of sterile products for the medical industry.

In short, without the invention of particle accelerators with energy sufficient to cause nuclear disintegrations, and without the further development of these accelerators and colliding beam machines to the elegant devices they are today, much of science and technology as we know it would not have happened. One can, of course, speculate on alternate paths of history which might have happened, but that is just speculation.

Present Contributions of Accelerator Development

The developments in accelerator science and technology during the last fifty years have been truly remarkable. In rapid succession there have been invented a variety of new types of accelerators: rectifier generators; electrostatic generators; cyclotrons; sector focused cyclotrons; betatrons; electron, proton, and heavy ion linear accelerators; electron and proton synchrotrons; alternating gradient focusing in synchrotrons and cyclotrons; and colliding beam storage ring devices. As each accelerator type has approached the limit of its practical and economical application, new accelerator ideas and techniques have emerged which

have allowed further advance. Altogether these advances have resulted in an increase in the energy of accelerators of 10 million-fold from the early rectifier generators to the large storage rings such as Tevatron-I at Fermilab and ISABELLE at Brookhaven which are now under construction. Further, the cost per unit energy of these machines has decreased dramatically, about a million-fold.

For applications of accelerators requiring lower energies but very high currents, the advances have been equally impressive. Electron accelerators with peak pulsed currents of about one million amperes have been developed for weapons simulation and flash radiography. For applications in controlled nuclear fusion and weapons research various types of induction linear accelerators with currents of 10,000 amperes or more are being built and tested. Recent advances in the development of very high current ion sources and in the use of space charge neutralization in accelerators indicate that we will soon have very high current, low emittance beams of light ions as well as electrons.

These impressive advances in accelerator capabilities have resulted both from the invention of new accelerating principles and techniques, and from the development of the necessary technology. Accelerator builders have been in the forefront of technological developments in ultrahigh vacuum, microwave, and pulsed power sources, application of computers to large scale systems control, and development of superconducting magnets and microwave cavities to mention only a few examples.

In addition to their application in basic research in high energy and nuclear physics, accelerators have also found wide application in numerous other research areas. The application of accelerators and accelerator-based technology within the Department of Energy is widespread. For example, accelerators are extensively used in the magnetic fusion program for neutral beam heating, for obtaining relevant neutron cross-section data, for beam-foil spectroscopy experiments to obtain data required for analysis of impurities in fusion plasmas, and as a source of neutron and other particles to study materials damage in future fusion reactors. They are used in materials and biological research studies using synchrotron light sources and pulsed spallation neutron sources, and for accelerated materials damage studies with charged-particle beams. Use of accelerators has allowed development of extremely sensitive techniques of isotopic impurity detection important in scientific dating and in study of possible ground water contamination from potential nuclear waste management sites. Accelerators operated by the Department of Energy are being used in clinical trials of promising new modalities for cancer therapy using heavy-ion, neutron, and pi-meson beams. In direct applications in energy technologies, ion accelerators are considered as promising drivers for inertial fusion and for tritium and nuclear fuel breeding. Free electron lasers now under development have potential application in defense, as inertial fusion drivers, and for advanced isotope separation techniques.

In medicine and industry extensive use is made of accelerators. For example, about 1000 accelerators are now installed in hospitals in the United States. One person in eight at some time in his life will be placed under one of these machines for treatment of cancer. Most of the surgical sutures and disposable medical apparatus in use has been sterilized by exposure to radiation, usually using beams from particle accelerators. In industry the use of radiation processed materials is widespread and is growing rapidly. A particular example is that of applying

insulating coating on wire, where radiation processing allows a better product, costing less, and using less volume. Such radiation processed wire is used, for example, exclusively in the 747 aircraft. Its use is growing rapidly in other applications such as telephone central offices.

One of the most rapidly growing applications of accelerators in industry is the production of integrated circuits. Integrated circuits go through at least one step of ion implantation during their manufacture. Some go through four to six steps. Electron beam lithography systems can be used to write the circuit patterns on masks, and synchrotron radiation x-rays from electron storage rings can be used to print these circuit patterns on semiconductor wafers. Electron beams can also be used to rapidly anneal out radiation damage which occurs during the ion implantation process. About 1000 ion implantation accelerators are now in use in industry. The use of synchrotron radiation x-rays in photo lithography is now being explored in research laboratories. We can anticipate very rapid future growth in these applications of accelerators to the production of integrated circuits.

Future Contributions of Accelerator Development

The above discussion of the present contributions of accelerator technological development to science and technology illustrate the extensive role which particle accelerators play in our society. There is every reason to believe that this role will continue and will grow. Many of the developments and applications are in their infancy and offer good prospects for the growing use of accelerators in an increasing number of ways. In high energy and nuclear physics, development of improved accelerator facilities and particle beam probes will continue to set the pace of research in these fundamental fields of science. Technological developments such as large scale application of superconductivity, intense beams of heavy ions, improved sources of intense microwave power, methods of beam cooling, and the ability to reduce the dimensions of high energy electron beams to few micron dimensions will open the way to new high energy and nuclear physics research facilities, and will provide a wealth of technological capability for use by others. In other areas of science improved synchrotron light sources and the expected development of free electron lasers are revolutionizing capabilities for research in materials studies, atomic and molecular physics, and biology. Intense pulsed sources of neutrons from accelerators will provide serious challenge to reactor based neutron sources and offer the possibility of research studies which would not have been possible in the past.

In medicine, research in the use of heavy ions and pi-mesons in cancer therapy, together with studies of accelerator configurations which might be suitable for location in hospitals, indicate that these new techniques for therapy will become common and will provide more effective treatment.

The development of very intense particle beams from accelerators at high energies will find application in many areas ranging from drivers for inertial fusion reactors to advanced weapons systems for national defense and improved methods for diagnostic investigation of transient phenomena.

There is a particularly bright future for the application of accelerators in industry, especially in the radiation sterilization, radiation processing, and microelectronics industries.

Despite these optimistic future prospects for the applications of accelerator technology, there are trends which can be seen which seem to offer challenges of which we should be aware, and about which we should try to do something. Some of these trends are discussed below.

1. The life-blood of experimental high energy physics rests upon the ability to investigate nature at ever smaller distances. This translates into the need for higher and higher energy accelerators. As discussed earlier, the accelerator community has responded beautifully and has achieved an increase in accelerator energy of a factor of about 10 million in the last fifty years, with a corresponding but slightly lower decrease in the cost per unit energy. With completion of the present generation of high energy physics accelerators now under construction, it is clear that we will have effectively exploited much of our present capability. We need to invest more in advanced accelerator R&D, both to find ways to utilize present accelerator concepts more effectively and at lower cost, and also to investigate radically new ideas which might make major increase in energy economically possible. To carry out these investigations it is especially important that we attract talented young people into accelerator research. Also, in considering proposals for new accelerator facilities, we should pay particular attention to those proposals which offer demonstrations of new concepts which can be further exploited in the future.

2. The cost of electric power to operate accelerators is growing so rapidly that it seriously impacts the use of larger facilities and limits their operation to only a fraction of the available time. Research under way in the use of superconducting magnets and superconducting rf cavities will somewhat alleviate these problems; however more research to improve the overall electrical efficiency of accelerators is needed and would have large payoff in operating expenses. There is every indication that research in this area will become increasingly important in the future.

3. The increasing cost of large research accelerator facilities clearly means that fewer of these facilities will be built, with longer times between new starts. There are obvious implications for the number of accelerator R&D groups which will exist in the future, and the need to develop new ways to keep these groups healthy and productive.

4. The buy-in cost of some applications of accelerators by industry is so large as to discourage industrial development of these applications. A good example is in the application of synchrotron light sources in the fabrication of integrated circuits. Fortunately

in this case arrangements are being made for proprietary use by industry of major synchrotron light sources. Laboratories, universities, and industry should be encouraged to explore opportunities for joint efforts to develop and prove out new accelerator applications.

5. Major new advances either in accelerator technology or in radical new accelerator ideas need to have inexpensive test beds in which these ideas can be tested and developed. Similarly the development of accelerators for some applications requires really large investments before the application can be demonstrated. We need to search for intermediate goals which will allow these technological developments to be demonstrated, and at the same time will allow practical pay off. These intermediate goals will often be found in some other field of research or in some other application area.

The concerns discussed above are real and could substantially inhibit the rate at which new accelerator technology and concepts will be developed and applied in science and technology. In part they are a result of the inevitable slowdown in the application of technology as accelerators become larger, more complex, and more expensive. However in part they are also a result of bureaucratic and institutional specialization. Federal funding for accelerator R&D is compartmentalized between agencies, and within agencies by program interests. This compartmentalization produces inflexibility and difficulty in achieving solutions to several of the problems mentioned above.

Most accelerator R&D groups have also become highly specialized to the accelerator needs of single programs. This makes it hard for them to develop synergistic R&D efforts which take advantage of accelerator R&D needs of different programs and agencies. There are exceptions. A few accelerator R&D groups have developed in recent years where research activities having a common technological thread are undertaken for a number of programs and agencies. It is not an accident that some of the best accelerator research and new ideas are coming from these groups.

Summary

In summary, the invention and development of particle accelerators and the associated technology has had a profound impact upon the progress which has been achieved in U.S. science and technology. It has been a joint effort of those who build accelerators and those who use them, each playing a vital role. The contributions from the past by the accelerator community are continuing now and there is every reason to believe that they will continue in the future. The accelerator community can and should be proud of their contributions.