IMPACT OF ACCELERATORS ON TECHNOLOGY

I. L. Morgan
Columbia Scientific Industries Corporation
Austin, Texas

Summary

Accelerators and accelerator technology has rapidly expanded into Medicine and Industry. The 2500 accelerators in the USA, which represent about 2/3 the worldwide census of accelerators are primarily devoted to practical applications, although the major impact on technology has been produced by a relatively few excellent facilities. Approximately 80% of the current accelerators in the USA are found to be in medical and industrial use representing a capital investment by industry of $200,000,000.

Of greater importance is their impact on the treatment of cancer, and the improvement or creation of better products for industrial and consumer use.

The development of new accelerators and techniques are required in order to insure continuing benefits to the public.

Introduction

The ultimate use of an ion or particle depends to a great extent on the energy, mass, and charge state of the particle. The usefulness depends largely on the intensity, energy resolution, control, and stability of the beam produced.

The progression of devices to accelerate ions, in order to satisfy man's insatiable curiosity about the nature of matter, started with Crookes, Thompson,[1] and others. Coolidge's development of the x-ray tube in 1921 signaled the beginning of a multi-hundred million dollar industry which would provide untold benefits to mankind.

The remarkable decade of the 1930's provided the scientific genius and experimental development of accelerators. Cockroft-Walton and their d-c accelerator, Lawrence[2] and the cyclotron, the electron linear accelerators, the positive ion linear accelerator by Alvarez, Van de Graaff, and the electrostatic accelerator provided the basic instruments necessary to open the doors into new worlds of discovery. The intellectual pursuit of the knowledge of the structure of the nucleus, nature of matter, and origin of the Universe now was possible.

The nuclear age was born during the second world conflict. Early in the 1950's, a concentrated effort on the peaceful uses of atomic energy, unnoticed by the public, brought forth new research, development, and industries devoted to providing social and economic benefits through the use of particle accelerators.

Accelerator Census

A recent survey of accelerator manufacturers and users has been accomplished in order to determine the application of accelerators and their impact on technology.

Industry estimates indicate that accelerators and accelerator technology have continued their rapid expansion into industry. A survey by E. A. Burrill[3] in 1968 indicated approximately 1,083 accelerators in the United States. In Figure 1 is shown the current estimated census of accelerators in the United States as of 1972. These accelerators represent approximately 2/3 of the world's population and does not include accelerators phased out due to age and obsolescence.

The largest increase in low energy accelerators in industry is due to the inclusion in this survey of electron beam welding devices, however, the rapid expansion of accelerators in petroleum exploration and increased activity in ion implantation contribute significantly to the low energy region. A large increase is noted in accelerators in the range of 3 to 10 MeV and is primarily due to the increase in medical radiotherapy units and electron processing accelerators for industry. The total number of accelerators estimated to currently be in use is 2,599 which represents a capital investment by industry of approximately 200 million dollars. If productivity is assumed to be 10 times the capital investment, one may conclude that the accumulative associated gross national product is in excess of 2 billion dollars.

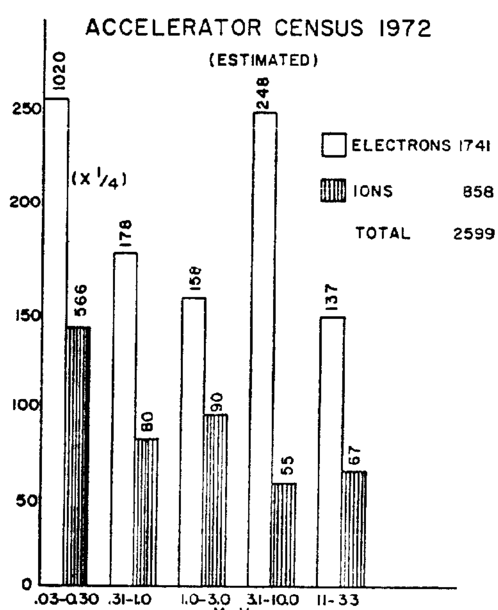

Fig. 1. Accelerator Census

Accelerator Applications

The large number of applications in which accelerators and accelerator technology may be used indicates their extreme versatility. Figure 2 shows a representative number of accelerator applications,[4] but is not inclusive of all applications since new techniques and processes are being discovered at a rapid rate.

In particular, this preliminary survey indicates that the most vivid impact of accelerators on technology has been in the areas of geophysics and in particular, petroleum exploration, radiation processing for the improvement or production of materials, electron beam welding of refractory metals, ion implantation for the production of semiconductors and high energy radiation therapy for the treatment of cancer.

The average time in for a newly discovered technique to move into industry and become a viable analytical tool is approximately eight years, and to become a standard production tool in industry is approximately fifteen years. Therefore, many of the accelerator applications which are now new and unique will in time find their way into routine industrial and medical applications and provide a greater impact on technology. In particular, air and water pollution analysis as conducted by the observation of x-rays stimulated by charged particle excitation or proton microbeams for scanning x-ray analysis or for microsurgery or even the recent observation of the Lymann series from highly excited oxygen atoms and specifically the advances in ion implantation and ion channeling, may eventually create completely new processes in semiconductor production.

Fig. 2. Accelerator Applications

Impact on Technology

Certain areas are striking examples of the impact of accelerators on technology and have produced a significant economic and social impact.

Geophysics and Petroleum Exploration

The recent energy crisis has created the need for newer and more reliable methods of exploration for petroleum and other energy resources. Within the last few years accelerator technology involving pulsed beams to produce neutron burst and the studies related to shielding and reactor design involving neutron thermalization time has rapidly moved into the area of exploration of petroleum.[5] The physics application is using an accelerator in a borehole in order to locate the exact strata containing petroleum through a study of thermalization time. Short bursts of neutrons are produced which immediately move out into a heterogeneous strata containing salt water, fresh water, or petroleum and are rapidly thermalized, and after diffusion are detected at the borehole. Figure 3 shows the observed die away curve. The observation of the die away time at various intervals gives a clear indication between fresh water, salt water, and hydrocarbons as shown in Figure 4. It is currently estimated that approximately 175 such accelerators are in use and are constructed into logging tools for use in petroleum exploration.[6] Although neutron-gamma logging has long been known and utilized in geophysical exploration, the die away technique due to accelerator technology has completely revolutionized the field of exploration.

The cost of logging a well may be of the order of several dollars per foot and the well may be of the order of 5 to 10 thousand feet and several thousand logs are made annually. The economic impact is immediately obvious and in excess of 100 million dollars annually. Readily discerning the differences between water and hydrocarbons greatly increases the reliability of petroleum discovery.

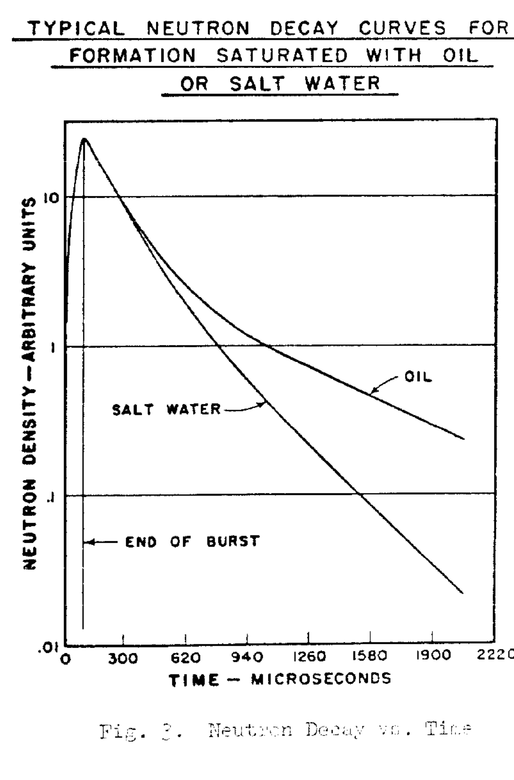

Fig. 3. Neutron Decay vs. Time

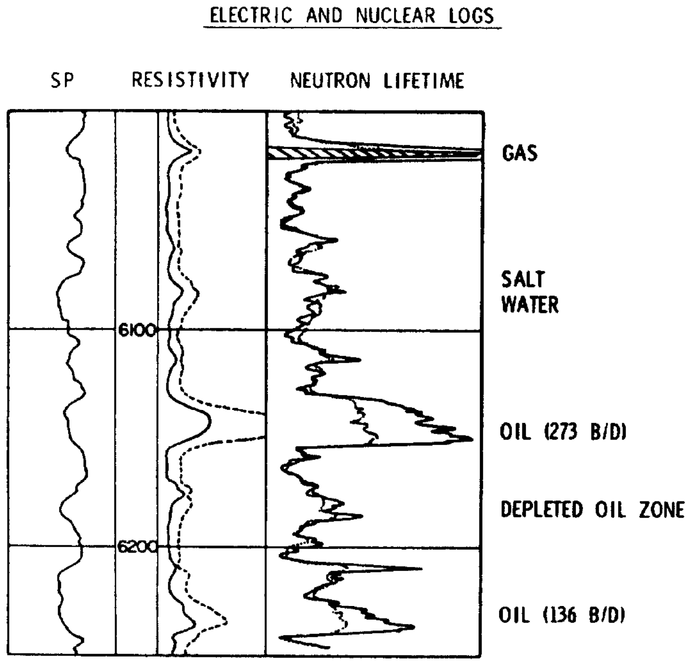

Fig. 4. Neutron Log of Borehole

Radiation Processing

Radiation processing using electron beams or high energy radiation produced by electron accelerators for the purpose of cross-linking plastics, radiation sterilization, and changing the physical properties of plastics is a direct result of accelerator technology. Industry estimates approximately 60 accelerators are providing electron beams for material processing[7] as schematically shown in Figure 5. Although this represents only a 50% increase in the number of accelerators the power specifications of recent accelerators have increased such that approximately a thousand kilowatts of radiation processing power is currently in use, and produces 140 million dollars of radiation processed products.

Industry anticipates that accelerator technology applied to this area will continue to accelerate as products such as heat shrinkable plastic, radiation polymerized paints, high temperature plastics, and "Permapress" clothing enjoy greater and greater market acceptance.

Electron Beam Welding

The current survey has included electron beam welding accelerators in the energy region of 30 keV to 300 keV. Electron beam welding may be considered a direct spinout of nuclear and space physics. Industry estimates there are approximately 1000 electron[8] beam welding units with an average welding capacity of 80 kilowatts and costing between 30 thousand and 100 thousand dollars. Electron beam welding is primarily centered in the refractory metal industry and permits the welding of titanium, zirconium, zircalloy, molybdenum, and tungsten in a vacuum or inert gas atmosphere. Their primary use is in welding nuclear fuel rod, jet engine components, and rocket nozzles. Industry anticipates this process will move into the steel and automotive market.

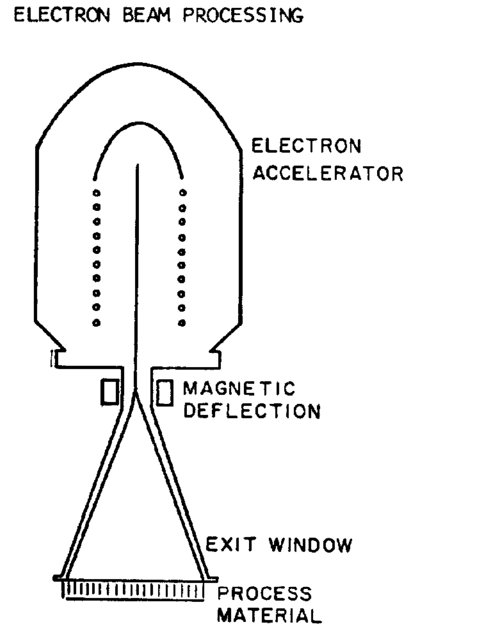

Fig. 5. Schematic of Radiation Processing Accelerator

Ion Implantation

Accelerators combined with new and improved ion sources have rapidly penetrated the ion implantation market for the production of semiconductors. In 1968, there were approximately eight accelerators involved in ion implantation on an experimental basis. At the end of 1972, industry estimated in excess of 100 accelerators as shown in Figure 6 as being employed in ion implantation of boron, phosphorous, or arsenic for the production of semiconductor diodes, solar cells, FET switches, and MOS devices[9]. Improved ion sources combined with masking techniques to produce MOS, MOS-LSI chips is projected to be the most frequent use of accelerators in ion implantation techniques. Total semiconductor production by this technique is not available, but reportedly one user produced 500,000 devices.

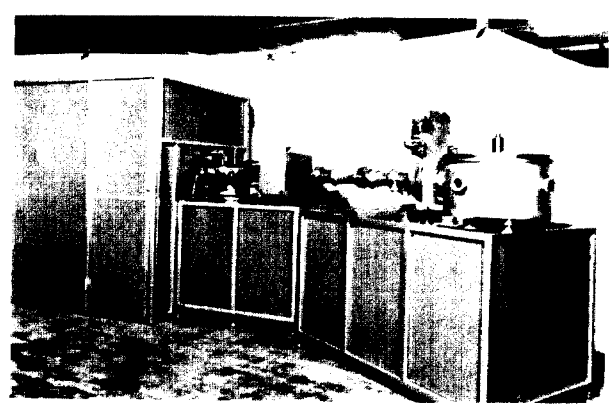

Fig. 6. Ion Implantation Accelerator and Vacuum Chamber

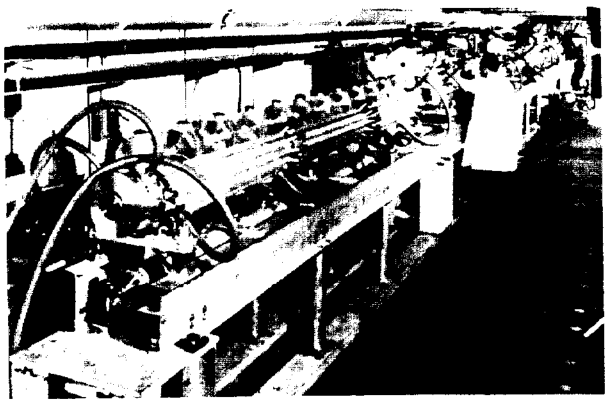

Fig. 7. Side Coupled Cavity Linear Accelerator Electron Prototype of 800 MeV Protron Accelerator

Fig. 8. Medical Linear Accelerator

Radiation Therapy

The most dramatic advance in accelerator utilization has been in the area of super high voltage x-ray radiation therapy in the treatment of cancer. In the late 1960's the development of a side coupled cavity[10] electron linear accelerator, as shown in Figure 7, at Los Alamos accelerated the development of electron and x-ray radiation medical therapy accelerators.[11] The electron linear accelerator or CLINAC increased from 79 units in 1968 to 193 units in 1972. A typical unit is shown in Figure 5 and is capable of 360° rotation about the patient. It is estimated that over a million people will have detected cancer in 1973 and 50% will undergo some form of chemotherapy plus radiation therapy. These radiation treatments will entail some 5 million individual irradiations at an estimated total annual cost of 500 million dollars. More impressive is the fact that combined radiation therapy and chemotherapy can more than double the five year life expectancy for persons with certain types of cancer. The increased productivity due to doubling the five-year life expectancy of this group of people is difficult to estimate but is possibly in the tens of billions of dollars.

Conclusion

Accelerator technology definitely has had impact both economically and socially and can so be demonstrated. New developments in accelerator technology and instrumentation is bound to have a continuing impact on technology as directly related to the intellectual social and economic benefit of mankind.

References

1. F. K. Richtmyer and E. H. Kennard, Introduction to Modern Physics, McGraw Hill Co. Inc. (1947)
2. IBID
3. E. A. Burrill (Private Communication)
4. High Voltage Engineering Corporation
5. R. Caldwell (Private Communication)
6. R. Caldwell (Private Communication)
7. Radiation Dynamics, High Voltage Engineering Corp. (Private Communication)
8. Sciati, Standard Hamilton (Private Communication)
9. Accelerators, Inc., Ortec
10. E. A. Knapp et.al., Rev. of Sci.Inst.Vol.39, No. 7 (979) 1968