ELECTRON BEAM PROCESSING: A NEW BUSINESS AND A NEW INDUSTRY

Andrew J. Stirling, AECL Accelerators[1]
10 Hearst Way. Kanata, ON. K2L 2P4 CANADA

SUMMARY: AECL Accelerators has built three high power 10 MeV industrial electron accelerators Two are in commercial use, one is operating in AECL's laboratories. The IMPELA[2] technology is proving more than adequately rugged for industrial use. Unattended operation is routine on one machine. The IMPELA accelerators have now more than 20 000 hours of service in total. But while the physics of accelerator design is an essential first step, and the engineering of a reliable design is the next, they are together little more than a beginning in building an electron processing industry. The other ingredients include proof of economic feasibility, the integration of accelerators into industrial plants and the development of new uses for electrons.

1 INTRODUCTION

The production lines of tire manufacturers or rubber glove plants are worlds away from the nuclear research laboratory. But particle accelerators may well be common to all. The industrial irradiation industry comprises those companies whose manufacturing processes use electron accelerators or radioisotopes to modify every-day materials in a beneficial way. Such products include computer disks, shrink packaging, tires, cable, plastic, hot water pipe, and sterile medical goods.

When electrons or gamma rays penetrate materials they create showers of lower energy electrons which, after many collisions create chemically active sites. These either break a bond or activate a site and promote a new chemical linkage. Breaking the bonds of a biological molecule usually renders it useless and kills the organism. Breaking an organic molecule changes its toxicity. Crosslinking a polymer strengthens it.

The industry relies on three basic accelerator technologies, DC accelerators to energies of 750 keV, Cockroft-Walton or Dynamitron accelerators to energies of 5 MeV and rf accelerators for energies to 10 MeV.

Electrons with energies up to 750 keV penetrate thin films and are used to cure coatings inks and paints.

Electrons with energies between 1 and 5 MeV are used to toughen and increase the fire and scuff resistance of wire cables. Tire plies are also partially electron cured so that they can be handled prior to vulcanization.

With 10 MeV energy, electrons sterilize syringes, gloves, or cosmetics and offer promise for new applications discussed later. This is the market in which AECL is active and is discussed here. This paper covers accelerator construction, proof of economic feasibility, integration of accelerators into plants and development of new uses for electrons.

2 ACCELERATOR CONSTRUCTION

In November 1992, AECL Accelerators completed a 10 MeV, 50 kW rf electron accelerator for E-BEAM Services in New Jersey. In December 1993, AECL Accelerators installed a similar 10 MeV, 50 kW accelerator for Iotron Industries of Canada in Vancouver, British Columbia. Both accelerators are AECL's IMPELA electron linear accelerators. [1]

AECL's IMPELA is a pulsed, on-axis coupled, L-Band, standing wave linac operating in a bi-periodic, pi/2 mode. Duty factor is 5%. Beam is injected, unbunched, from a pulsed, annular grid, dispenser cathode gun. Rf power is supplied by a 4-stage, grounded collector, modulating anode klystron via a 4-port circulator. Impela is constructed to some 2300 controlled drawings, calling on standard and custom components. The key item is the 3m high-purity copper accelerating structure of 58 cavities brazed face to face.

3 COMMISSIONING

During commissioning each component is brought to full operating performance and sequentially integrated together. The vacuum envelope, baked during manufacture is evacuated to the target pressure and power is then applied to the structure at ever increasing levels. Raising the power in carefully chosen steps heats and field-etches the inside of the accelerating cavities to permit ever increasing vacuum levels. As the vacuum increases so the sustainable power level increases. Commissioning from zero to full power has been accomplished in as little as 8 hours of operation.

4 INTEGRATION OF ACCELERATOR IN PLANT

It is essential to shield the staff and public from the electron beam, yet maintain the flow of a large volume of material into the irradiation chamber. The radiation shielding design must therefore balance cost against, adequacy of shielding, and flexibility to introduce products of various sizes and types.

For industrial electron accelerators the most cost effective shielding materials are concrete or earth. Three meters of concrete are required to adequately shield a 10

MeV electron accelerator. Over-designing the shield is an intrusion into the plant and is expensive. Under-designing is dangerous. Limiting product path dimensions to minimize cost limits flexibility for use with new products. AECL has developed a shielding design that optimizes flexibility and is safe and economic.

Options for orienting the accelerator are vertical (either up or down),or horizontal. The client preference will be dictated by the type of conveying equipment typical in the client’s industry. The IMPELA accelerator can be used in either horizontal or vertical mode.

5 AVAILABILITY AND OPERATING EXPERIENCE

The availability of the IMPELA accelerator at Iotron in Vancouver is 98.9% over its life. Between the three operating IMPELAs, there are more than 20 000 hours of operating experience. Operation at one is unattended for two shifts each day. Operators do not necessarily have any formal technical education The high availability is principally a result of the inherently rugged design and careful attention to engineering detail Also important is diagnostic software and data that are available to service staff who can monitor many parameters in the accelerator.

6 CALIBRATION-DEVELOPMENT OF THE CDose SYSTEM

Sterilization requires that a method be available for documenting that every box has been exposed to a known dose and that the dose distribution is sufficiently uniform that all items are sterile and that none is overdosed. Traditionally this relied on measuring energy and power before a production lot and monitoring machine parameters throughout. While adequate, much more can be done by monitoring the charge deposited in the beam stop and correlating it with the beam position. Indeed, an on-line measurement of both energy [2] and absorbed dose [3] can be made. AECL has developed these systems and patented them. A key advantage of the on-line dose system is that the orientation of items in the box can be confirmed, on-line.

The on-line dose monitoring system uses the following technique. If one measures the electron flux density and uses the spatial information that is available from instantaneous position of the scanned electron beam and product position on the conveyor, a two-dimensional image of absorbed dose can be produced.

The key to on-line calculation of absorbed dose is the transmission of electrons through the product, even though most of the electron energy is deposited in the product. For example, about half of the incident charge is trapped in the product and half passes through the product during sterilisation. The amount of charge collected by the beam stop can then be correlated to the deposited energy (dose) in real time. Figure 1 shows a typical tray layout and the image reconstructed by the AECL CDose system.

The electron beam energy can also be verified. The statistical nature of the interaction of an incident 10 MeV electron results in a distribution of dose and charge as a function of depth. A conventional measurement of energy is made by generating a depth-dose curve that is compared with data for known energies. The new energy calibration method makes use of the lesser known depth-charge distribution for an on-line measurement of energy. The charge depositions as a function of depth in aluminum for 9, 9.5, 10, 10.5 and 11 MeV electrons have been calculated with Monte Carlo codes. A vertically segmented beam stop measures the integrated charge deposition for two regions of the distribution. The ratio of the charge deposited in one region, to the total is a direct measure of energy.

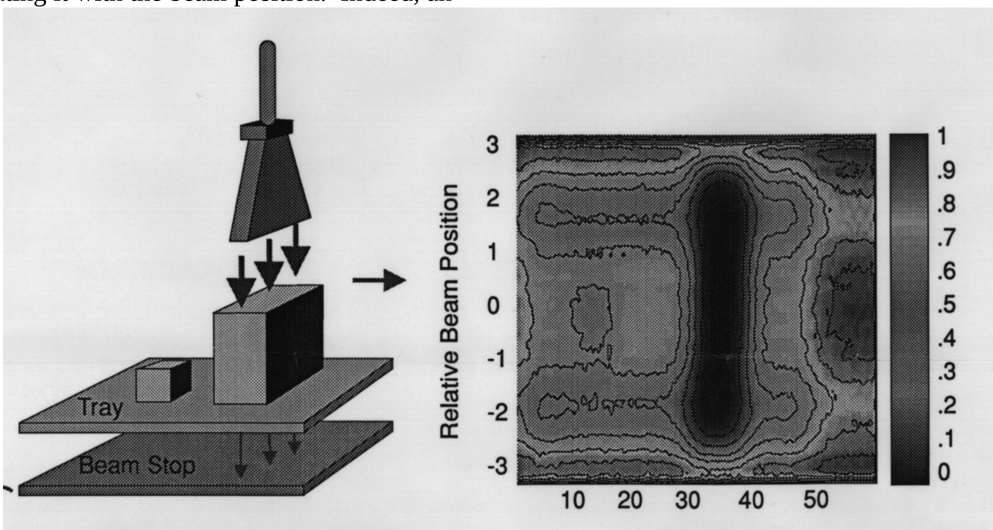

Figure 1

7 ECONOMIC FEASIBILITY

The function of an electron irradiator is to treat products at the lowest possible cost. The key specifications which control treatment cost are

Power (which controls throughput)
Efficiency of use of electrons
Reliability, and
Operating cost, e.g. utilities

The economic feasibility of an electron irradiation is established by cost per unit of product treated. The cost for electron sterilization must compete with that from Cobalt 60 gamma rays and from ethylene oxide gas.

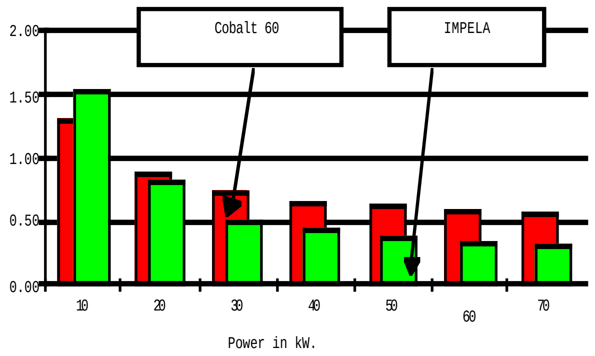

Figure 2: Cost of Sterilization as a Function of Power (throughput)

The cost for electron sterilization is a strong function of volume treated (Figure 2). Until the AECL IMPELA was developed the maximum reliable power level for electron accelerators was between 10 and 20 kW. At this power, gamma rays from cobalt 60 provide strong price competition. At higher powers the economics of the process becomes limited more by the availability of the product to be treated in any one place rather than the power of the accelerator.

8 NEW APPLICATIONS

IMPELA's power and reliability level opens new horizons for the use of electron beams for modifying materials.

8.1 Viscose

Rayon, cellophane and acetate fibers are common consumer products and are made from wood. To produce rayon, dissolving pulp (consisting essentially of pure cellulose) is dissolved in chemicals. Viscose liquid is an intermediate product: an oily yellow solution of cellulose in carbon disulfide from which the viscose staple fibre or cellophane etc., are regenerated as fibers or films.

Electron processing renders the cellulose more accessible to chemicals and reduces the amount of alkali, carbon disulfide, and acid used in the process. In addition to potential savings of about US $3 million per annum for a typical plant, the lower chemical demand translates into reduced emissions of polluting chemicals. Electron processing may allow a plant to stay in operation under current emission standards, or expand its operation without the need for further pollution control.

8.2 Electron Beam Cured Composites

The curing of advanced composites represents another substantial market yet to be exploited. The opportunity is to greatly reduce the cost to produce complex advanced composite components used in the aerospace industry (such as wing components) by curing them with electron beams. These benefits could also be important to other transportation products and to structural components. The US Advanced Research Projects Agency (ARPA) has announced $30 million worth of support for two aerospace companies to develop processes to reduce composite manufacturing costs. Electron beam curing is core effort. Several multi-national aerospace and chemical manufacturers have entered Cooperative Research and Development Agreement (CRADA) with the US Department of Energy to develop the process. The CRADA group recently announced the discovery of chemicals which will make most traditional composite resins electron beam curable.

9 POTENTIAL MARKETS

9.1 Food Irradiation

Given the heightened concerns in the US over bacteria in meat and poultry products and the large volume of hamburger and chicken consumed, the food irradiation market has tremendous potential. There are a number of applications within the food area where irradiation offers important benefits, the most important being the elimination of pests and microbes in agricultural commodities and the elimination of food borne disease primarily in meat and poultry.

The growth of the market for irradiation to eliminate food borne disease has not developed as expected, perhaps due to public fears of irradiation of food with radioactive cobalt 60 or because food producers have not historically been liable for food safety. However, a number of recent developments suggest that demand for food irradiation may increase significantly in the future. Recent well-publicized incidents involving contaminated beef and poultry has led the US Department of Agriculture to require more stringent testing by food suppliers. This is expected to result in reductions in acceptable pathogen levels. At the same time, public concerns over the use of irradiation for food products have been shown to be reduced.

9.2 Environmental

In the environmental control sector, markets are believed to exist for irradiation of municipal sewage, hospital and airport wastes and to eliminate organics from waste streams. The primary obstacle to the development of markets in the environmental sector is the availability of cheaper alternatives (e.g. dumping). There is no doubt that society will move towards a commitment for higher quality treatment provided the technology has been demonstrated at an appropriate level. A recent proposal to the City of Edmonton shows that the sterilization of sewage sludge by electron beam is competitive with other technologies in cost and superior in performance. However that city chose to retain a disposal method that requires land be taken out of use as being less expensive.

NOTES

1 AECL is Atomic Energy of Canada Ltd. AECL Accelerators is a Division of AECL.

2 IMPELA is a registered trademark of AECL.

REFERENCES

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[2] C.B. Lawrence, On-Line Energy Calibration, Paper presented at the ASTM Third International Workshop on Dosimetry For Radiation Processing, Ste-Adèle, Quebec, 1995 Oct.

[3] C.B. Lawrence, On-Line Absorbed Dose Monitoring, Ibid