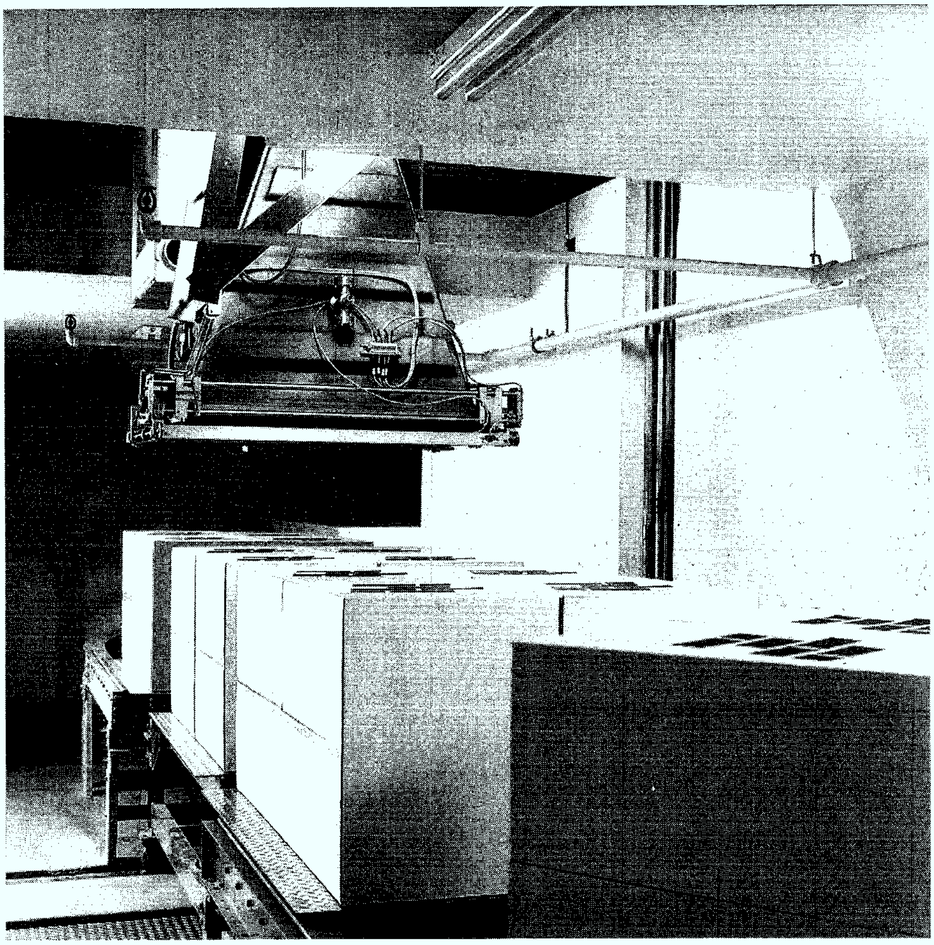


Electron beam irradiation is often used in industry to improve the quality of manufactured goods or to reduce production cost.

irradiation using isotopes, industrial irradiation uses three accelerator configurations, each type defining an energy range, and consequently the electron penetration depth. For energies up to 750 kV, the accelerator consists of a DC potential applied to a simple wire anode and the electrons extracted through a slot in a coaxially mounted cylindrical cathode. In the 1-5 MeV range, the Cockcroft-Walton or Dynamitron(R) accelerators are normally used. To achieve the high potentials in these DC accelerators, insulating SF_6 gas and large dimension vessels separate the anode and cathode; proprietary techniques distinguish the various commercial models available. Above 5 MeV, the size of DC accelerators render them impractical, and more compact radiofrequency-driven linear accelerators are used.

Irradiation electron beams are actually 'sprayed' over the product using a magnetic deflection system. Lower energy beams of up to 750 keV are able to penetrate thin films, and processes have been developed for curing coatings such as inks and paints on metals and papers. Examples include beer cans, gift wrap, and glossy packaging where multicolour labels must be printed at high speed and there is no time for the ink to dry; electron beams are able to 'cure' instantly.

Another widespread electron-treated product is shrink film for packaging, where a polyethylene film, crosslinked during stretching, will, when heated, revert to its original shape. This 'memory' effect has widespread use in shrinkable connectors, such as tubes for electrical solder joints. Shrink tubes are also used to join gas pipelines and have also been made delicate enough for use by surgeons to reconnect human blood vessels.

Electron beams between 1 and 5 MeV are widely used to toughen and increase the fire and scuff resistance of wire cables. A similar process is used to increase the service temperatures of polyethylene pipes and tanks for hot water.

At energies up to 10 MeV, electrons sterilize syringes, gloves, cosmetics and pharmaceuticals, and recently, electron-curable epoxies have been developed for the production of aerospace parts. Electron treatments cure parts more rapidly than heat and induce less stress.

In France, the first plant for food irradiation using an accelerator will ensure that mechanically-deboned chicken is salmonella-free. Despite considerable research, the use of electron accelerators for food treatment is still largely undeveloped, the financial arguments remaining unconvincing.

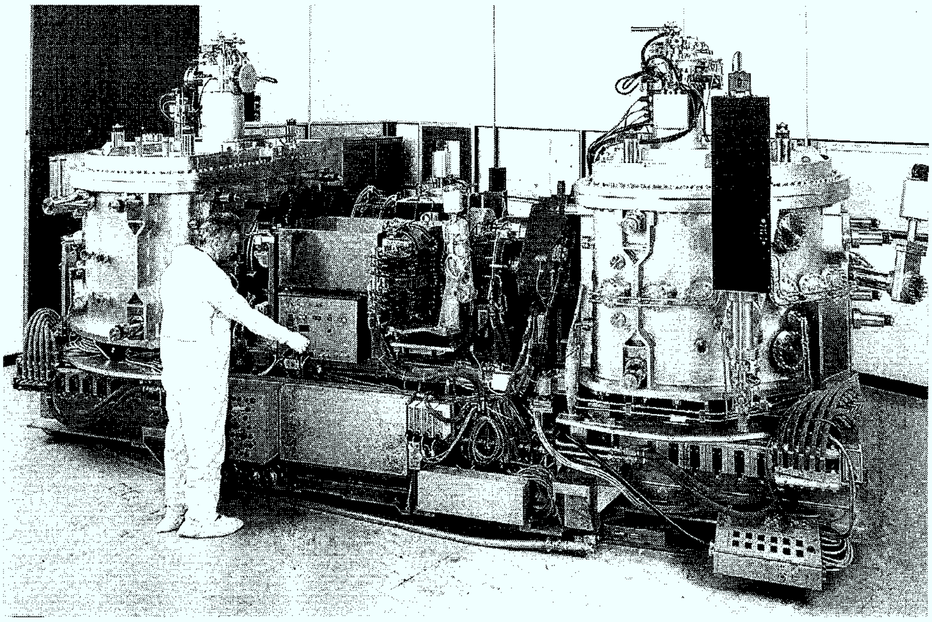
Environmental applications are also largely undeveloped. Accelerators have been shown to disinfect sewage sludge so that it can be spread directly onto farmland, gardens or parks, with acceptably low pathogen levels. Pilot trials are also in progress to use electron beams to eliminate nitrous and sulphurous oxides from power station flue gas.

The economic and political environment of radiation processing is constantly changing. Although accelerator development opens up new technology, costs and regulations are also increasing. The technological exploitation of accelerators with energies to up to 5 MeV is seen as mature; 10 MeV electron accelerators have been upgraded to industrially significant power levels, and system improvements have reached the levels of reliability and efficiency demanded for operation by industry.

From Andrew J Stirling, AECL Accelerators, Kanata, Ontario, Canada

Thin layer activation

The reliability of industrial equip ment is substantially influenced by wear and corrosion; monitoring can prevent accidents and avoid down-time. One powerful tool is thin layer activation analysis (TLA) using accelerator systems. The information is used to improve mechanical design and material usage; the



X-ray lithography is a technique for replicating patterns by shadow printing. HELIOS 1, a compact racetrack synchrotron for X- ray lithography, was assembled and tested prior to installation at IBM's semiconductor manufacturing facility at East Fiskill, NY, USA. (Photo Oxford Instruments plc, UK)

technology is used by many large companies, particularly in the automotive industry, e.g. Daimler Benz.

A critical area of a machine component receives a thin layer of radioactivity by irradiation with charged particles from an accelerator - usually a cyclotron. The radioactivity can be made homogeneous by suitable selection of particle, beam energy and angle of incidence. Layer thickness can be varied from 20 microns to around 1 mm with different depth distributions; the position and size of the wear zone can be set to within 0.1 mm. The machine is then reassembled and operated so that wear can be measured.

An example is a combustion engine comprising piston ring, cylinder wall, cooling water jacket and housing wall, where wear measurements on the cylinder wall are required in a critical zone around the dead-point of the piston ring. Proton beam bombardment creates a radioactive layer whose thickness is known accurately, and characteristic gamma radiation from this radioactive zone penetrates through the engine and is detected externally. Measurements can be made either of the activity removed from the surface, or of the (reduced) residual activity; wear measurement of the order of 10^{-9} metres is possible.

The particles employed are usually protons, deuterons or alpha particles with energies from 6 to 10 MeV giving sub-millimetre penetration depths in solids. One useful reaction uses cobalt-56, produced by 11 to 14 MeV proton bombardment of iron-56, where the reaction rate changes rapidly with energy, resulting in a variation of induced activity with penetration. Beam current will be adjusted in the range up to 10 microamps so that the radiation dose is below 0.1% of the critical dose at which radiation damage can occur.

For large machine parts, a proton beam extracted from a cyclotron via a thin window is directed onto the device some 150 mm away.
A precision 3-dimensional alignment system rotates the machine part around any axis to produce the required depth profile.

The gamma radiation is measured by conventional sodium iodide detectors with fast electronics; several radionuclides may be produced but energy discrimination and analysis of the radioactive decay can unravel the different nuclides.

Thin layer activation procedures have been developed in numerous irons, steels and alloys as well as sintered and other hard materials. Procedures have recently been developed in collaboration with industry for ceramics and several other hard materials.

From H. Schweickert and P. Fehsenfeld, Kernforschungszentrum Karlsruhe Gmbh (KFK), Germany

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X-ray lithography

X-ray lithography is a technique for replicating patterns by shadow printing. The required pattern is created on a mask which is then positioned accurately in front of a wafer coated with a sensitive material known as a photoresist. X-rays shone through the mask cast a shadow on the wafer, thereby transferring the pattern from mask to wafer, and short X-ray wavelengths make high spatial resolution possible. The process is now being developed as a technique for producing the next generation of microchips and components.

Synchrotron radiation is broad spectrum, high intensity electromagnetic radiation generated when high energy electrons are deflected in a magnetic field (see page 20). Produced in multi-GeV electron synchrotrons and storage rings, synchrotron radiation provides the best X-ray sources for lithography, where high intensities (beam currents) are