Electrostatic accelerators are used to deposit ions in semiconductors
The semiconductor industry relies on the implanting of impurities in semiconductors (doping).

This is critical in integrated circuit manufacturing.

One way of doping this is to fire ions into the material from an accelerator with its penetration dependent on the energy, hence they can be placed accurately in the material.

Ion implanting is the only method to accurately control the ion position from the equipment settings.
In the US, potential markets for industrial electron beams total $50 billion per year.

33% wire cable tubing
32% ink curing
17% shrink film
7% service
5% tires
6% others

When polymers are cross-linked, can become:
- stable against heat,
- increase tensile strength, resistance to cracking
- heat shrinking properties etc.
Food Irradiation

‘Cold pasteurization’ or ‘electronic pasteurization’ uses electrons (from an accelerator) or X-rays produced using an accelerator.

The word ‘irradiated’ or ‘treated with ionizing radiation’ must appear on the label packaging.

In the US all irradiated foods have this symbol

Foods authorized for irradiation in the EU:

Lower dose  Higher dose
Other uses in industry

Hardening surfaces of artificial joints
Removal of NO$_x$ and SO$_x$ from flue gas emissions
Scratch resistant furniture

Treating waste water or sewage
Purifying drinking water

Irradiating topaz and other gems with electron beams to change color
Neutrons reveal structure and dynamics

Neutrons show where atoms are

When the neutrons collide with atoms in the sample material, they change direction (are scattered) — elastic scattering.

Detectors record the directions of the neutrons and a diffraction pattern is obtained. The pattern shows the positions of the atoms relative to one another.

Neutrons show what atoms do

3-axis spectrometer with rotatable crystals and rotatable sample

Crystal that sorts and forwards neutrons of a certain wavelength (energy) — mono-chromatized neutrons

When the neutrons penetrate the sample they start or cancel oscillations in the atoms. If the neutrons create phonons or magnons they themselves lose the energy these absorb — inelastic scattering.

...and the neutrons then counted in a detector.

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Neutrons reveal structure and dynamics

**Neutrons see more than X-rays**
X-rays are scattered by electrons; neutrons by atomic nuclei. With X-rays it is easiest to see atoms that have many electrons. Hydrogen, for example, which has only one electron, is not so easy to see. With neutrons, all kinds of atoms are visible.

**Neutrons reveal inner stresses**
A hole has been punched in an important metal aircraft part. Does the part match up? Neutron diffraction can show how much the distance between the atoms has changed and hence the internal forces remaining round the hole after it has been punched.

**Neutrons show what atoms remember**
Of their earlier positions when they move randomly in relation to each other in liquids and melts. Even here there is in fact some local order. The atoms cannot move infinitely close to each other. Some distances are more common than others.

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Neutrons reveal structure and dynamics
Spallation target

- \( \sim 2.3 \cdot 10^{13} \) (4 \( \mu \)C) ppp on to TS-1 tantalum coated tungsten target (40 pps)
- \( \sim 15-20 \) neutrons/proton, \( \sim 4 \cdot 10^{14} \) neutrons/pulse
- primary neutrons from spallation: evaporation spectrum (E \( \sim 1 \) MeV) + high energy tail
Unblocking oil pipes

- **Asphaltenes** are a complex mixture of molecules that can sometimes block oil pipes.

- Research to more easily *predict* and *prepare* for the formation of asphaltene deposits

- Result in *fewer blockages* and *big savings* for the oil industry.

“ISIS allowed to understand more clearly how asphaltenes aggregate, an important observation from a flow assurance point of view and should allow more efficient extraction of hydrocarbons in the future.”

-Edo Boek, Schlumberger Cambridge Research
Stresses in Airbus A380 Wing

- Aircraft manufacturer Airbus has used ISIS since 2006
- Research into aluminum alloy weld integrity for aircraft programs
- Residual stresses from welding cause weaknesses and possibility of cracks
- ISIS neutrons look deep inside engineering components to measure stress fields
Understanding infant lung structure

- Natural lung *surfactant* allows oxygen into bloodstream
- Absence in *premature babies* causes *breathing difficulties*
- ISIS mimicked change in lung capacity to discover how *proteins* and *phospholipids act together*
- Helping to *develop synthetic lung surfactants* which can be more *precisely targeted* at clinical needs to help *save babies’ lives*
Fast neutron testing for semiconductor industry

- Atmospheric neutrons collide with microchips and upset microelectronic devices every few seconds
- 300 times greater effect at high altitude
- ISIS enables manufacturers to mitigate against the problem of cosmic radiation
- Increased confidence in the quality and safety of aerospace electronic systems
Cargo scanning

Cargo containers scanned at ports or border crossing

Accelerator-based sources of X-rays can be far more penetrating (6 MV) than Co-60 sources.

Container must be scanned in 30 s.
“deuterium-tritium nuclear fusion reactions will generate neutron fluxes in the order of \(10^{18} \text{ m}^{-2}\text{s}^{-1}\) with an energy of 14.1 MeV that will collide with the first wall of the reactor vessel”

**International Fusion Material Irradiation Facility**

40 MeV  
2\cdot125 mA linacs  
CW deuterons, 5 MW each  
Beams will overlap onto a liquid Li jet to create conditions similar to in a fusion reactor

To de-risk IFMIF, first a test accelerator ‘LIPAc’ is being built

Installation of ‘LIPAc’ test accelerator has started in Japan
ADS systems
Transmutation of nuclear waste isotopes or energy generation

Major challenges for accelerator technology in terms of beam power (> 10 MW) and reliability
Radiocarbon ($^{14}$C) formation and decay

- formed by interaction of cosmic ray spallation products with stable N gas

\[ \overline{1}n + ^{14}_7N \rightarrow ^{15}_7N \rightarrow ^{14}_6C + ^1_1H \]

- radiocarbon subsequently decays by $\beta^-$ decay back to $^{14}$N with a **half-life of 5730 y**

\[ ^{14}_6C \rightarrow ^{14}_7N + \beta^- + \bar{\nu} \]

Radiocarbon dating was first explored by W.R. Libby (1946), who later won the Nobel Prize.

The activity of radiocarbon in the atmosphere represents a balance of its production, its decay and its uptake by the biosphere, weathering, etc.

Which of these three things might change through time and why?
1) As plants uptake C through photosynthesis, they take on the $^{14}$C activity of the atmosphere.
2) Anything that derives from this C will also have atmospheric $^{14}$C activity (including you and I).
3) If something stops actively exchanging C (it dies, is buried, etc.), that $^{14}$C begins to decay.

\[ A = A_0 \cdot e^{-\lambda t} \]

where present-day, pre-bomb, $^{14}$C activity = 13.56 dpmin/g C
For more accuracy, isolated C-14 from other isotopes
“AMS” = Accelerator Mass Spectrometry
Finally, just one more application …

**Detecting wine fraud**

Use ion beam to test the bottle of “antique” wine – chemical composition of the bottle compared to a real one.

“In a recent and spectacular case, American collector William Koch sued a German wine dealer, claiming four bottles – allegedly belonging to former U.S. president Thomas Jefferson – purchased for 500,000 dollars, were fake. The case has yet to be settled”.

- [http://www.cosmosmagazine.com](http://www.cosmosmagazine.com)