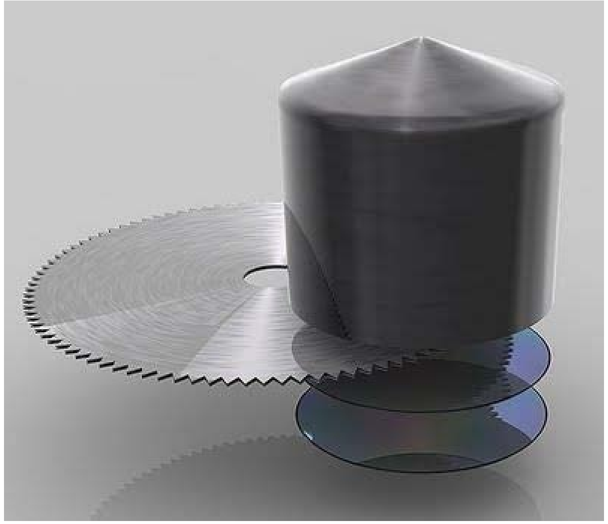
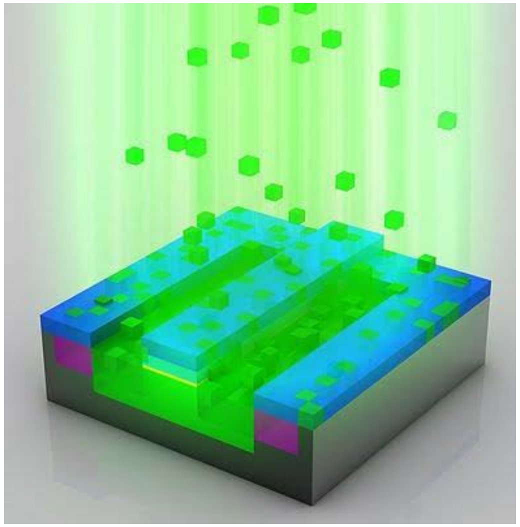
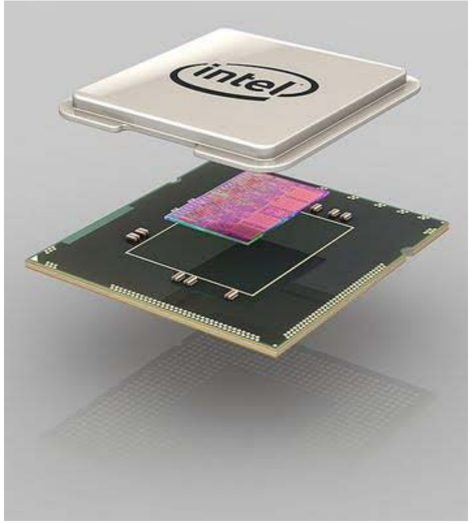
Ion Implantation



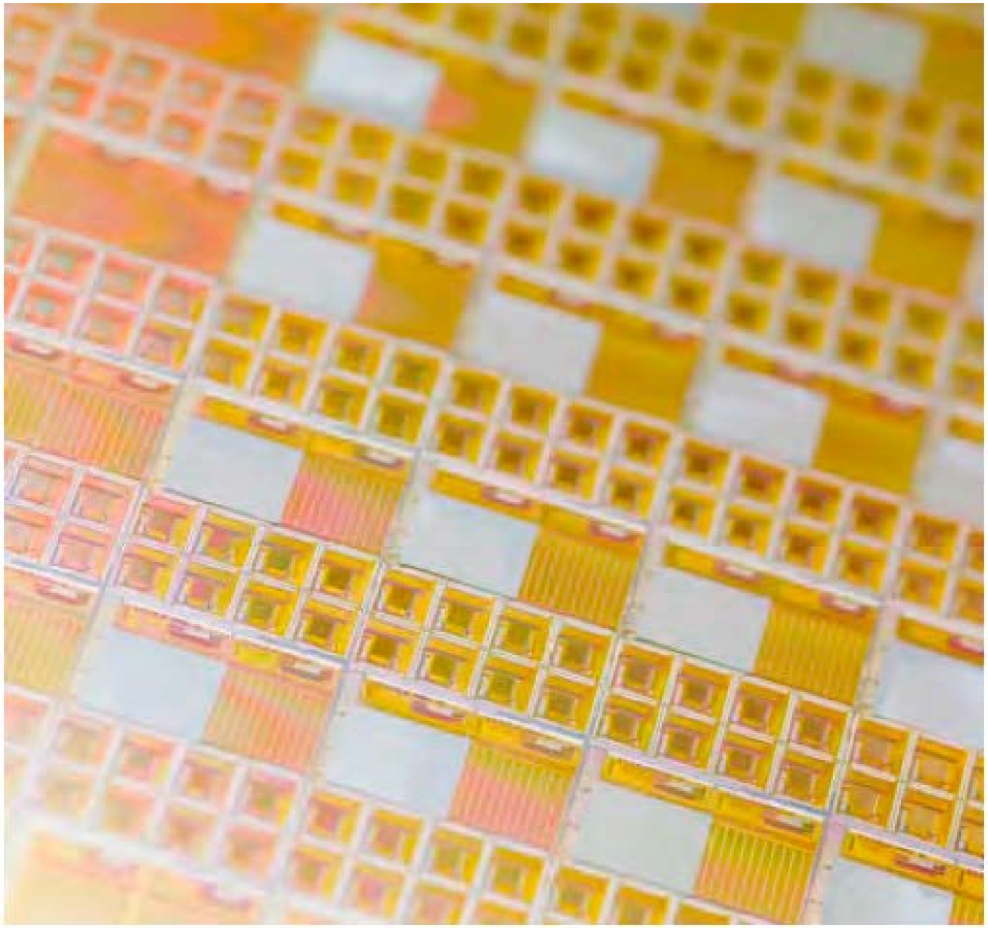




Electrostatic accelerators are used to deposit ions in semiconductors

Ion Implantation

- 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.



About 10,000 accelerators are in use worldwide to "dope" the silicon or germanium base to create electronic circuitry for computer chips. *Photo: Reidar Hahn, Fermilab*

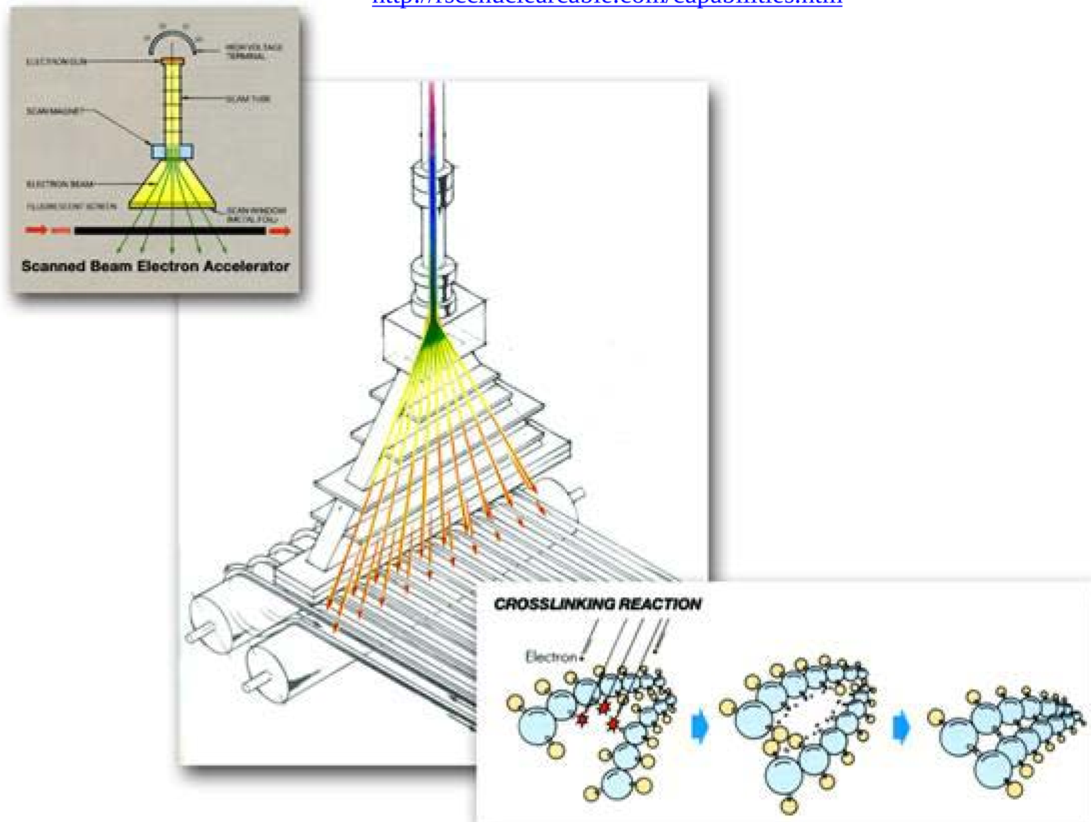
High-Current Ion Implanters		Medium-Current Ion Implanters		High-Energy Ion Implanters	
Ion Current	**Energy**	**Ion Current**	**Energy**	**Ion Current**	**Energy**
Up to 30 mA	1 keV to 200 keV	1 micro A to 5 mA	2 keV to 900 keV	up to 1 mA	up to 5 MeV

Electron Beam Processing

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

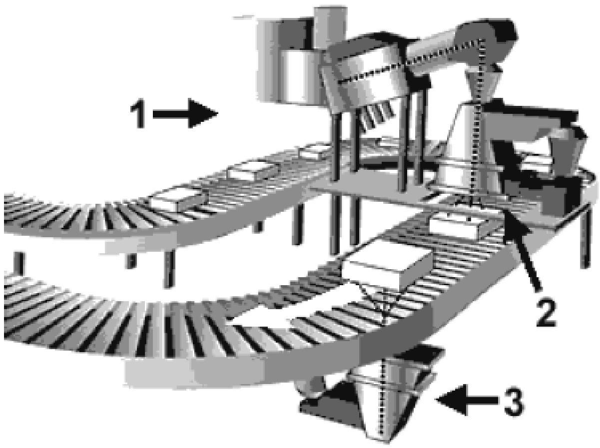
http://rsccnuclearcable.com/capabilities.htm



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

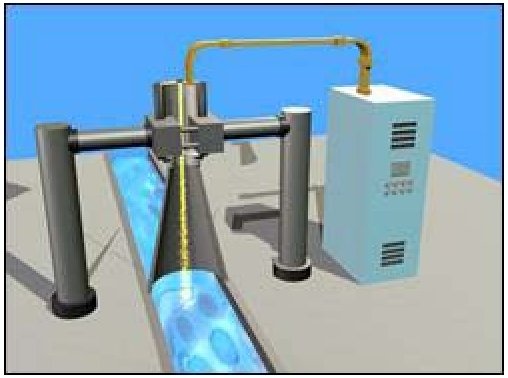
Foods authorized for irradiation in the EU:

Lower dose → Higher dose

Other uses in industry

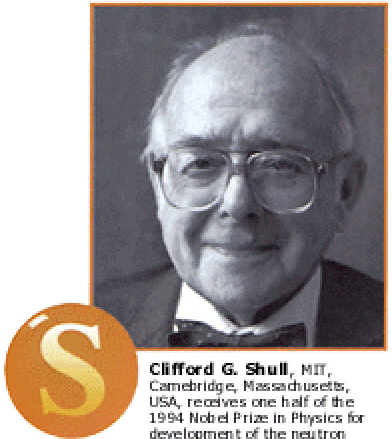
Hardening surfaces of artificial joints
Removal of NO_x and SO_x from flue gas emissions
Scratch resistant furniture

Treating waste water or sewage
Purifying drinking water

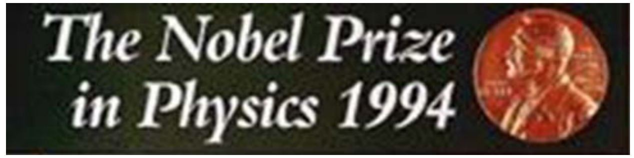


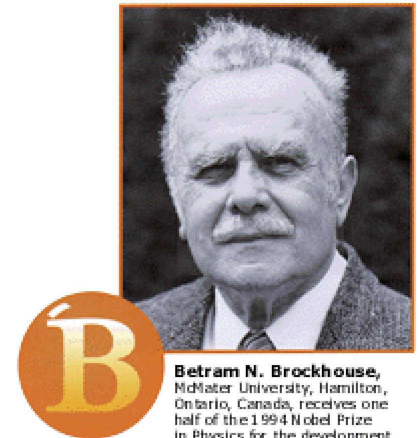
Irradiating topaz and other gems
with electron beams to change color

Neutrons reveal structure and dynamics



Clifford G. Shull, MIT, Camebridge, Massachusetts, USA, receives one half of the 1994 Nobel Prize in Physics for development of the neutron diffraction technique.

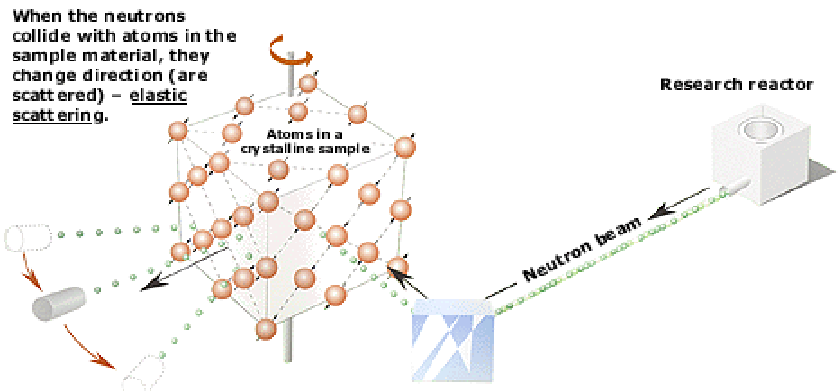


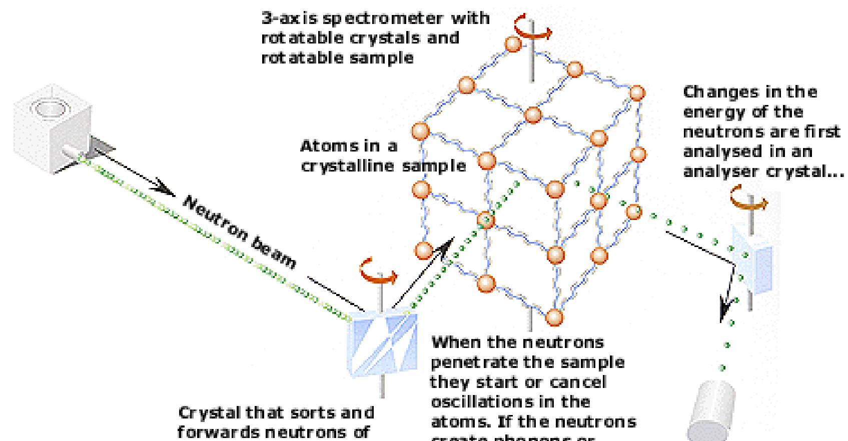


Betram N. Brockhouse, McMater University, Hamilton, Ontario, Canada, receives one half of the 1994 Nobel Prize in Physics for the development of neutron spectroscopy.

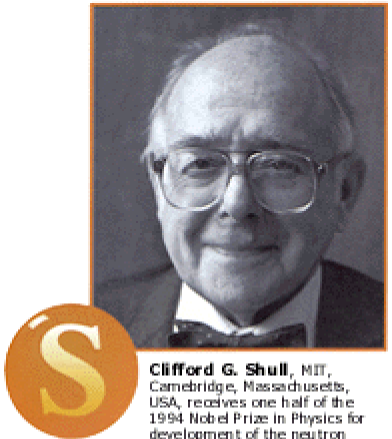
Neutrons show where atoms are

Neutrons show what atoms do

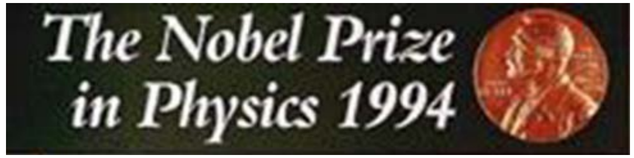


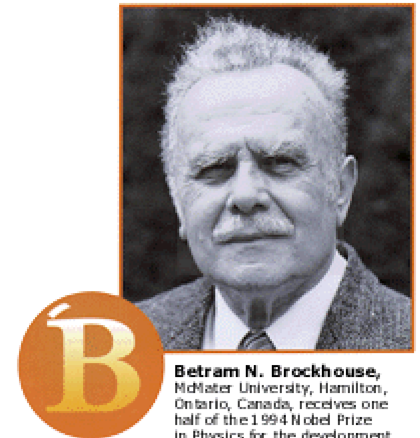


Neutrons reveal structure and dynamics



Clifford G. Shull, MIT, Camebridge, Massachusetts, USA, receives one half of the 1994 Nobel Prize in Physics for development of the neutron diffraction technique.

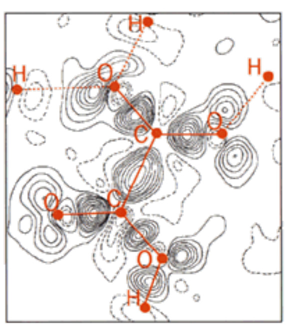




Betram N. Brockhouse, McMater University, Hamilton, Ontario, Canada, receives one half of the 1994 Nobel Prize in Physics for the development of neutron spectroscopy.

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.

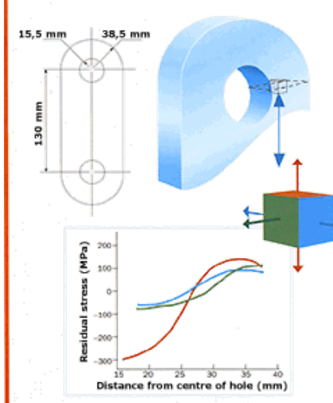


Lay a neutron diffraction map (showing the positions of the nuclei) over an X-ray diffraction map (giving the distribution of the electrons). It is then clear that the electron density is shifted in relation to the positions of the atomic nuclei. Since a chemical bond involves a shift in electron position, a direct picture of the chemical bond is obtained in this way.

Neutrons reveal inner stresses

A hole has been punched in an important metal aircraft part.

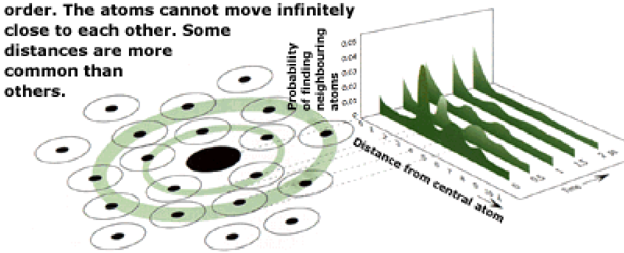
Does the part match up? Neutron diffraction can show how much the distance between the atoms has changed and hence the internal forces remaining round the hole after it has been punched.



The curves show local expansion forces (positive) and compression forces (negative) in different directions (red, green and blue) in an aircraft part (Saab39 Gripen).

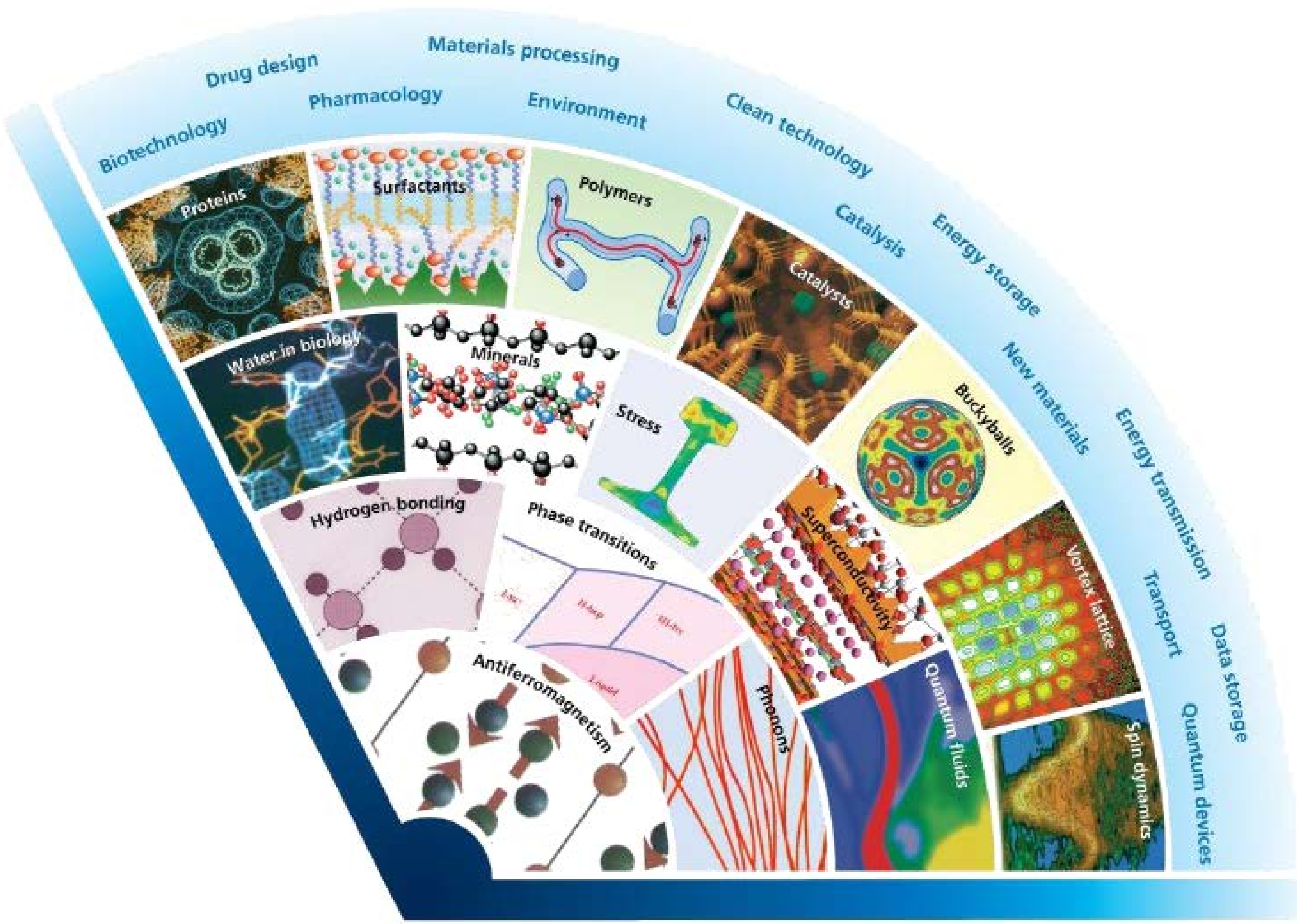
Neutrons show what atoms remember

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.



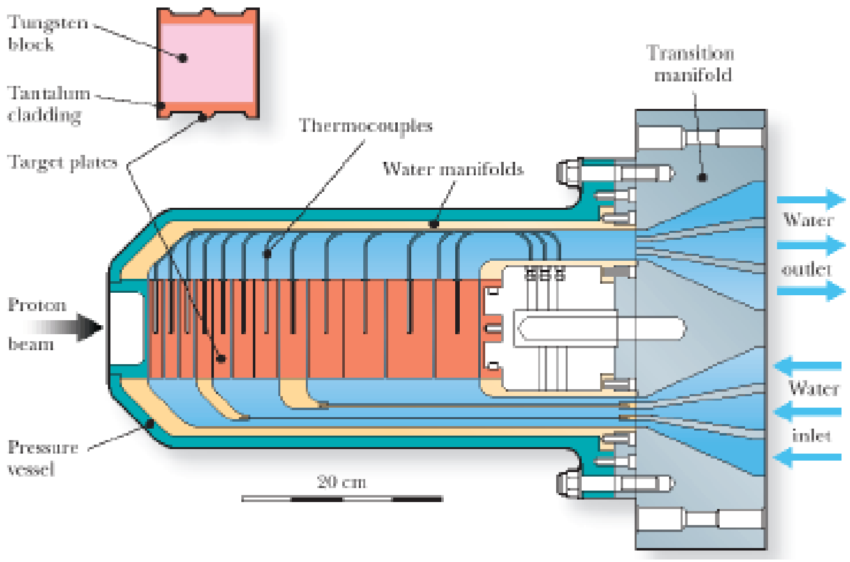
The time curve t = 0 shows the positions for liquid bismuth. The other curves show how the positions of the atoms change with time (1 ps = one millionth of a millionth of a second) seen with inelastic neutron scattering. Corresponding "memory functions" can also be measured in magnets e.g. near the Curie temperature, the temperature at which magnetic order shifts to disorder.

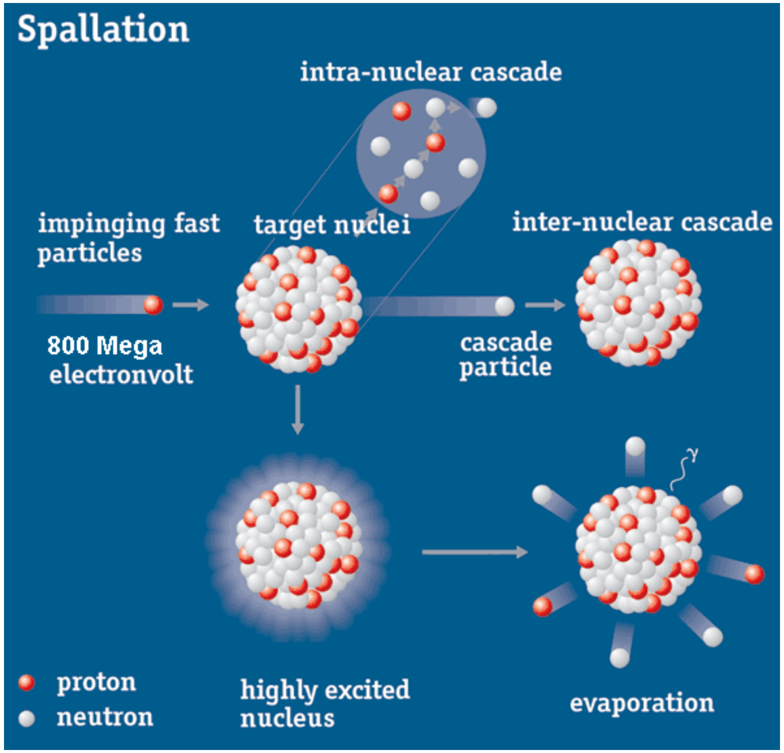
Neutrons reveal structure and dynamics



Spallation target

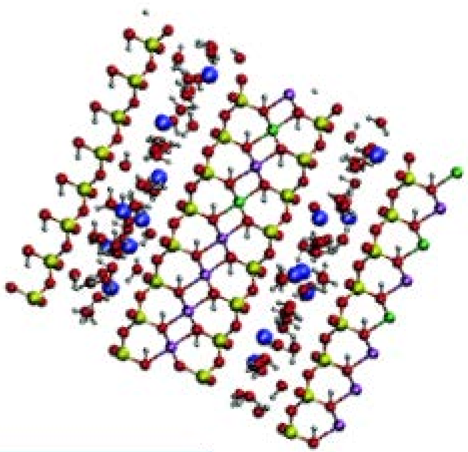
- ~ $2.3 \cdot 10^{13}$ (4 μC) ppp on to TS-1 tantalum coated tungsten target (40 pps)
- ~15-20 neutrons/proton, ~$4 \cdot 10^{14}$ neutrons/pulse
- primary neutrons from spallation: evaporation spectrum (E ~ 1 MeV) + high energy tail





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.

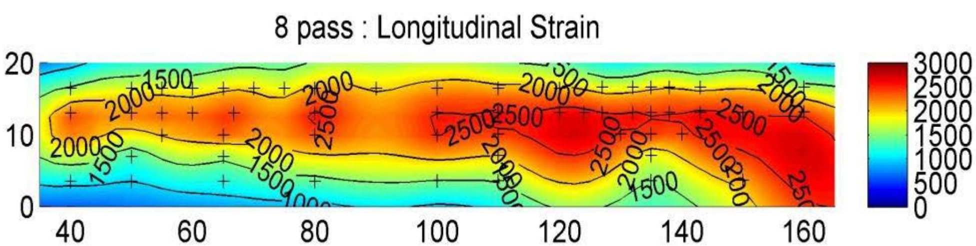


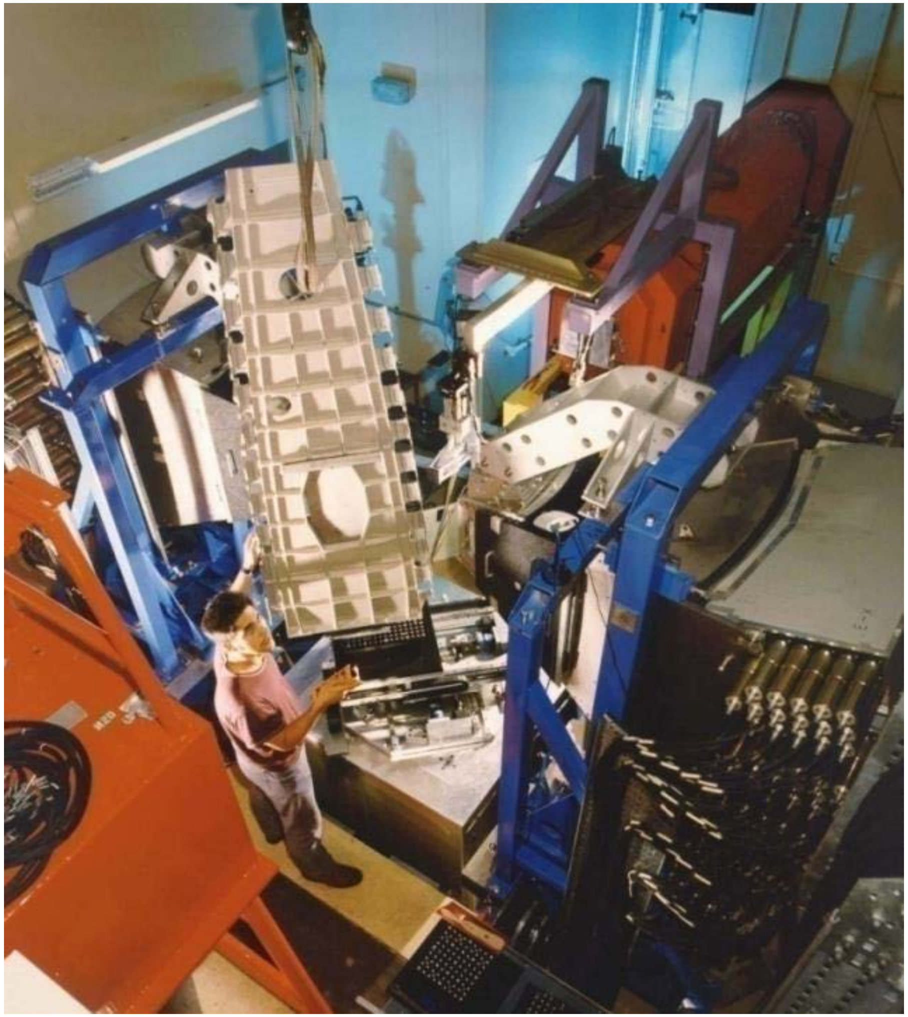
"ISIS allowed to understand more clearly how asphaltenes aggregate, an important observation from a flow assurance point of view and should allow more efficient extraction of hydrocarbons in the future."
-Edo Boek, Schlumberger Cambridge Research

Schlumberger

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

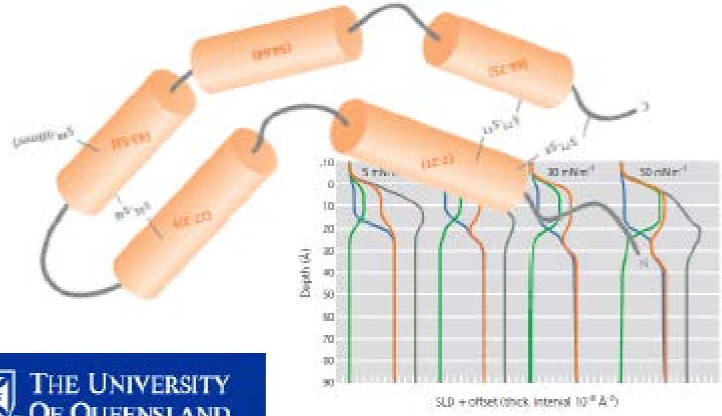




AIRBUS

Understanding infant lung structure

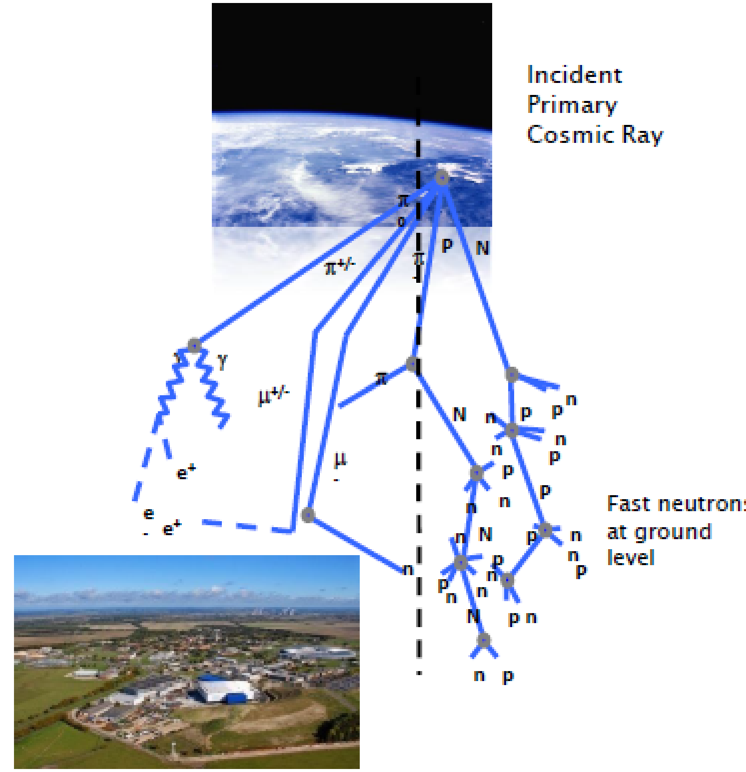
- Natural lung ***surfactant*** allows oxygen into bloodstream
- Absence in ***premature babies*** causes ***breathing difficulties***
- ISIS mimicked change in lung capacity to discover how ***proteins*** and ***phospholipids act together***
- Helping to ***develop synthetic lung surfactants*** which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



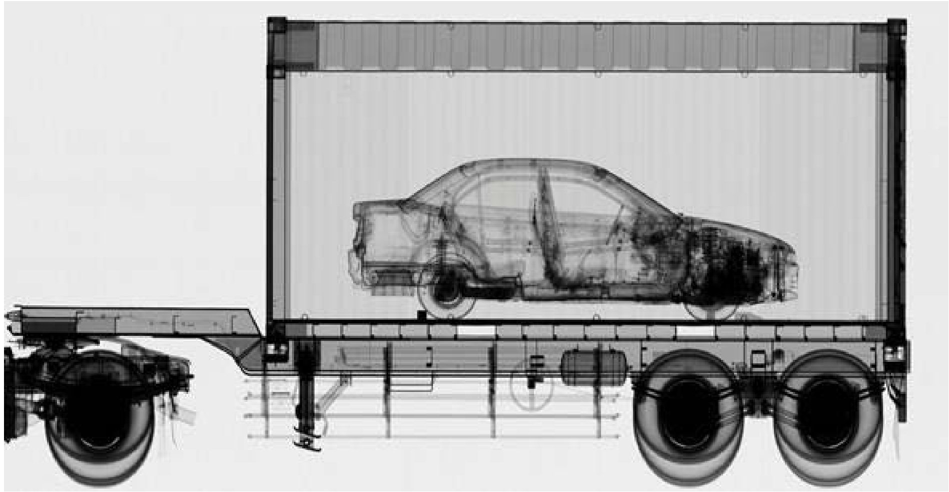
THE UNIVERSITY OF QUEENSLAND AUSTRALIA

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



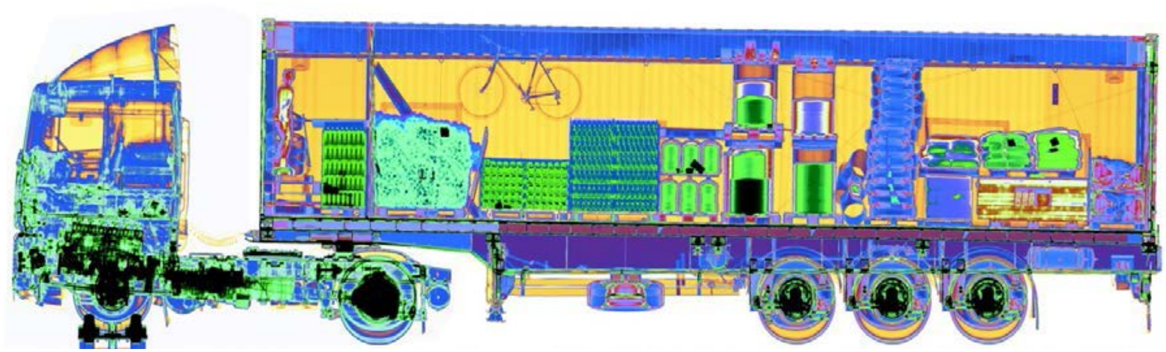
Cargo scanning



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.



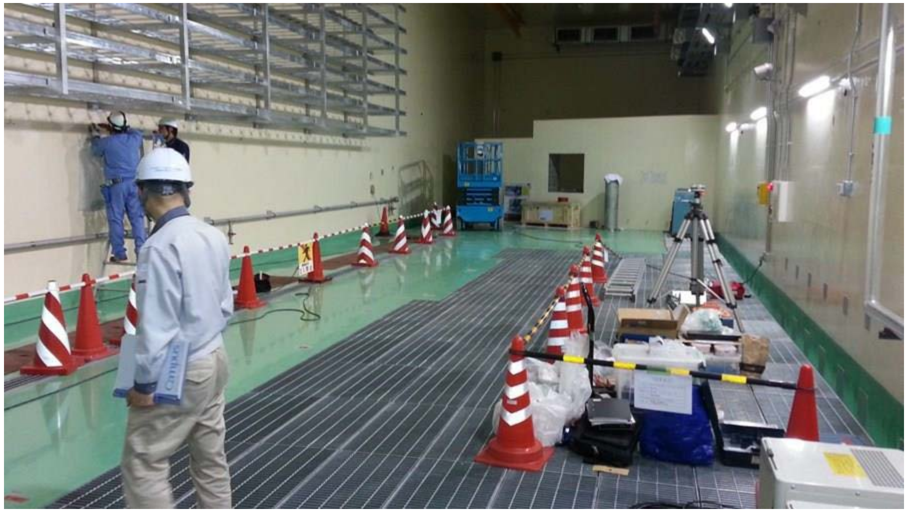
Materials testing for fusion

"deuterium-tritium nuclear fusion reactions will generate neutron fluxes in the order of 10^{18} $m^{-2}s^{-1}$ 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
2·125 mA linacs
CW deuterons, 5 MW each
Beams will overlap onto a liquid Li jet to create conditions similar to in a fusion reactor

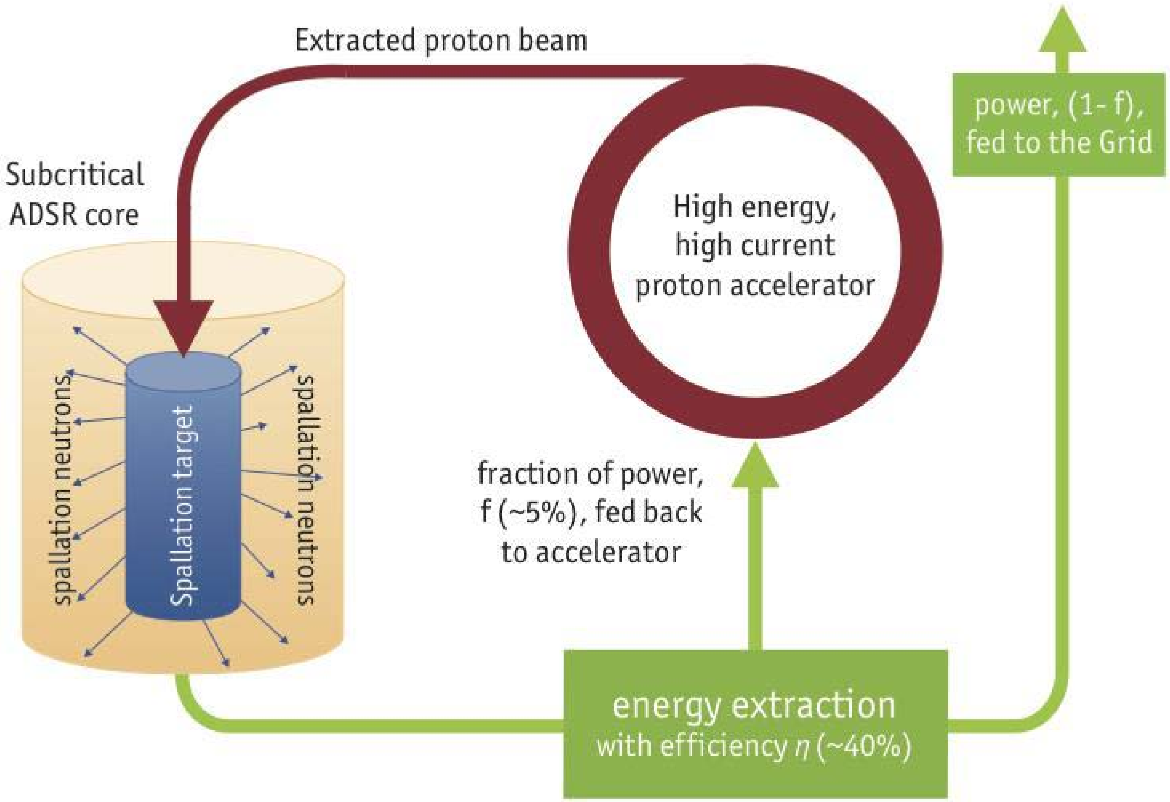
To de-risk IFMIF, first a test accelerator 'LIPAc' is being built



Installation of 'LIPAc' test accelerator has started in Japan

ADS systems

Transmutation of nuclear waste isotopes or energy generation



Thorium

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

$$^{1}_{0}n + ^{14}_{7}N \rightarrow ^{15}_{7}N \rightarrow ^{14}_{6}C + ^{1}_{1}H$$

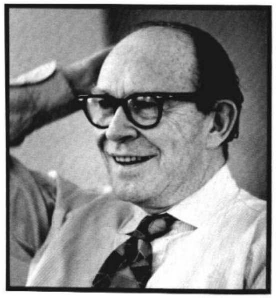
- radiocarbon subsequently decays by β^- decay back to 14N with a ***half-life of 5730 y***

$$^{14}_{6}C \rightarrow ^{14}_{7}N + \beta^- + \bar{\nu}$$

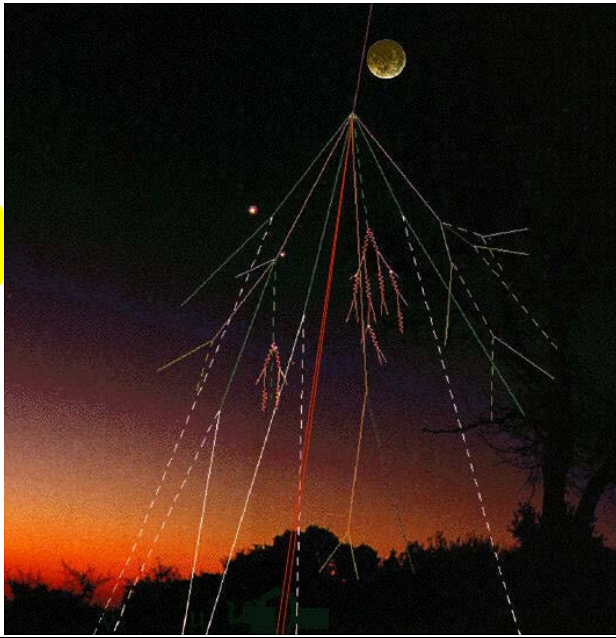
Radiocarbon dating was first explored by W.R. Libby (1946) , who later won the Nobel Prize.

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?

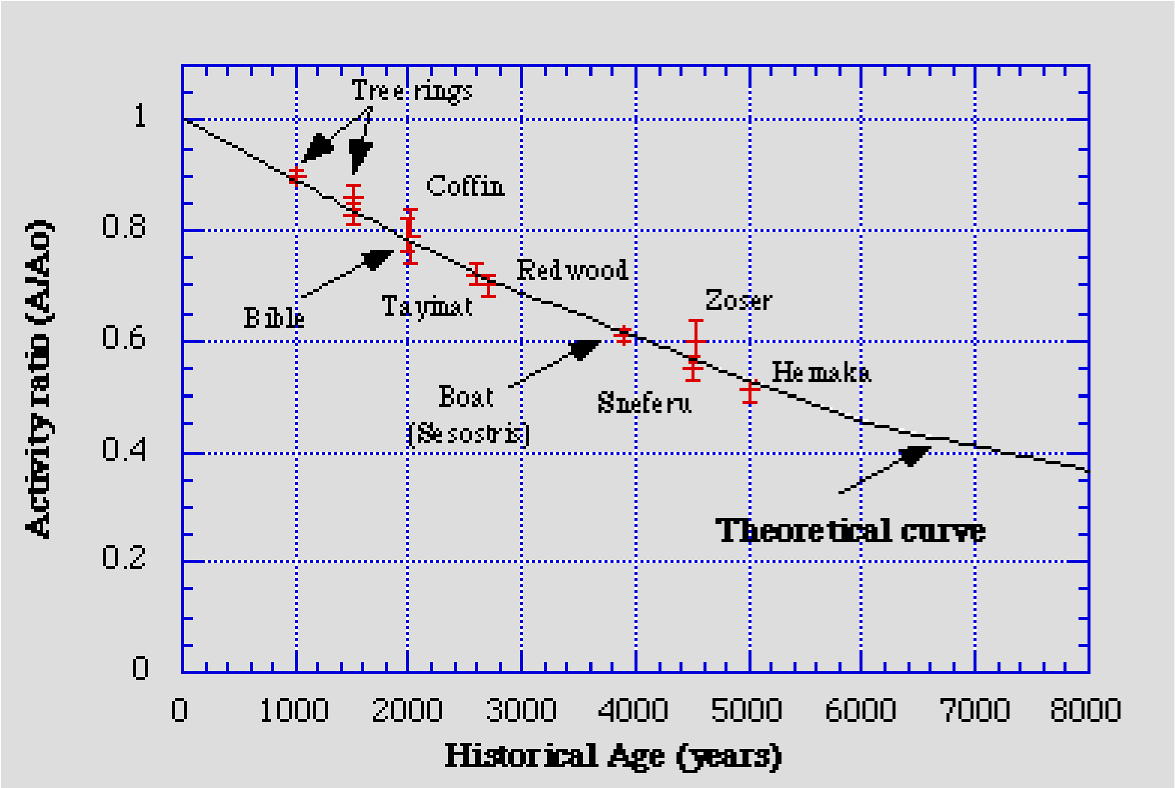


Willard Frank Libby



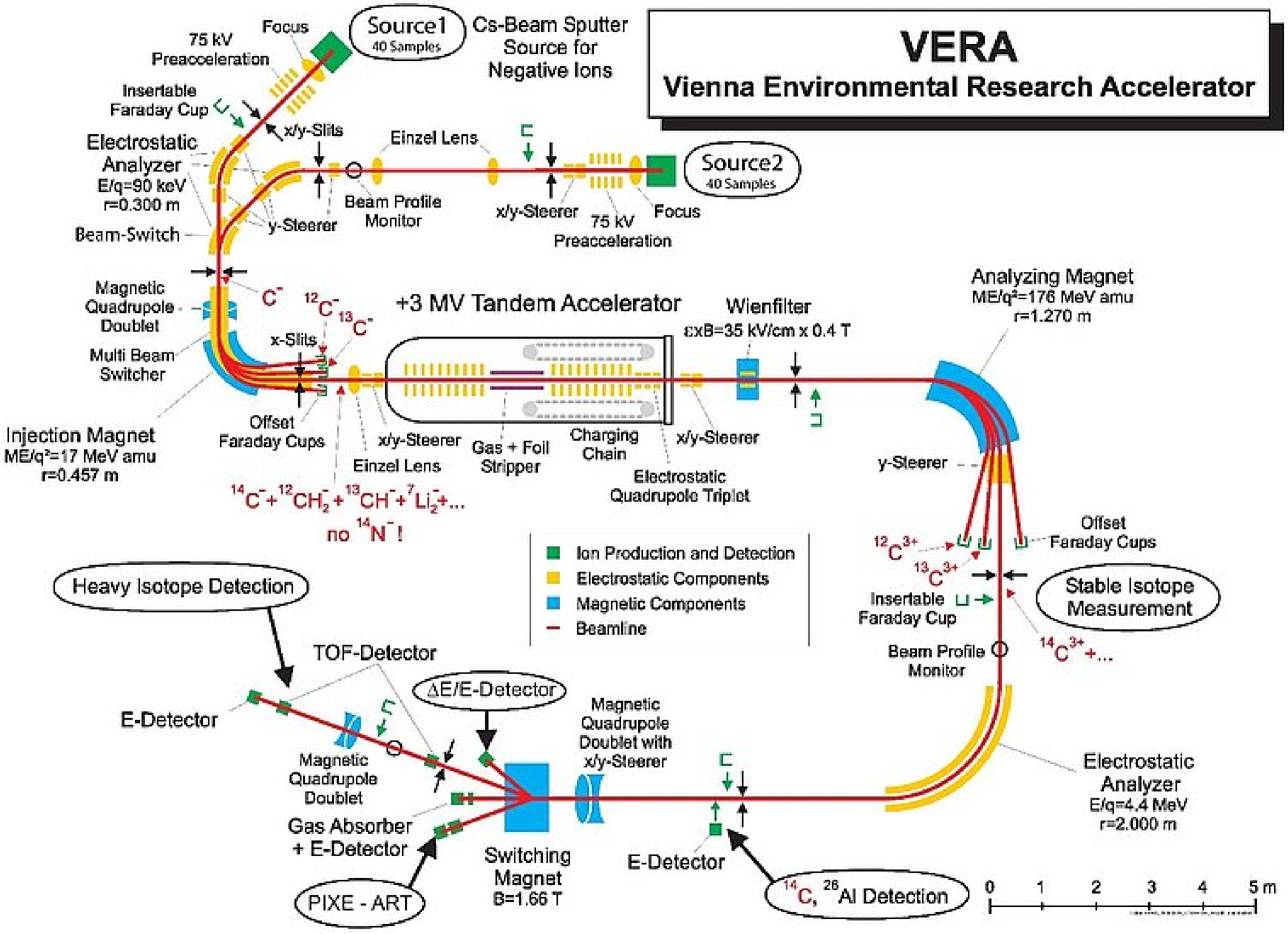
Radiocarbon Dating

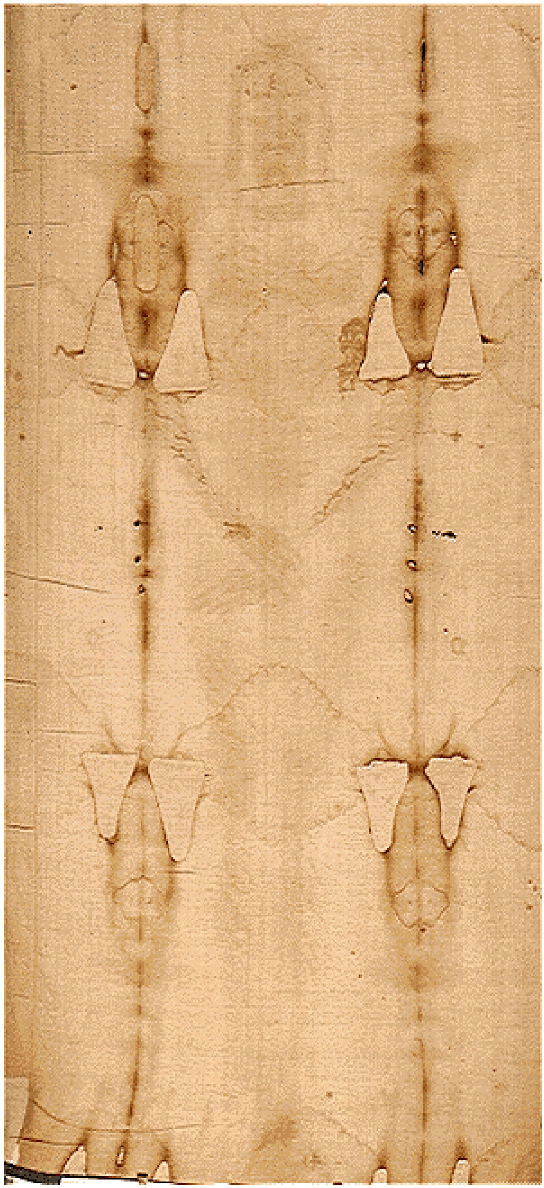
1) As plants uptake C through photosynthesis, they take on the ^{14}C activity of the atmosphere.
2) Anything that derives from this C will also have atmospheric ^{14}C activity (including you and I).
3) If something stops actively exchanging C (it dies, is buried, etc.), that ^{14}C begins to decay.



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

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

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