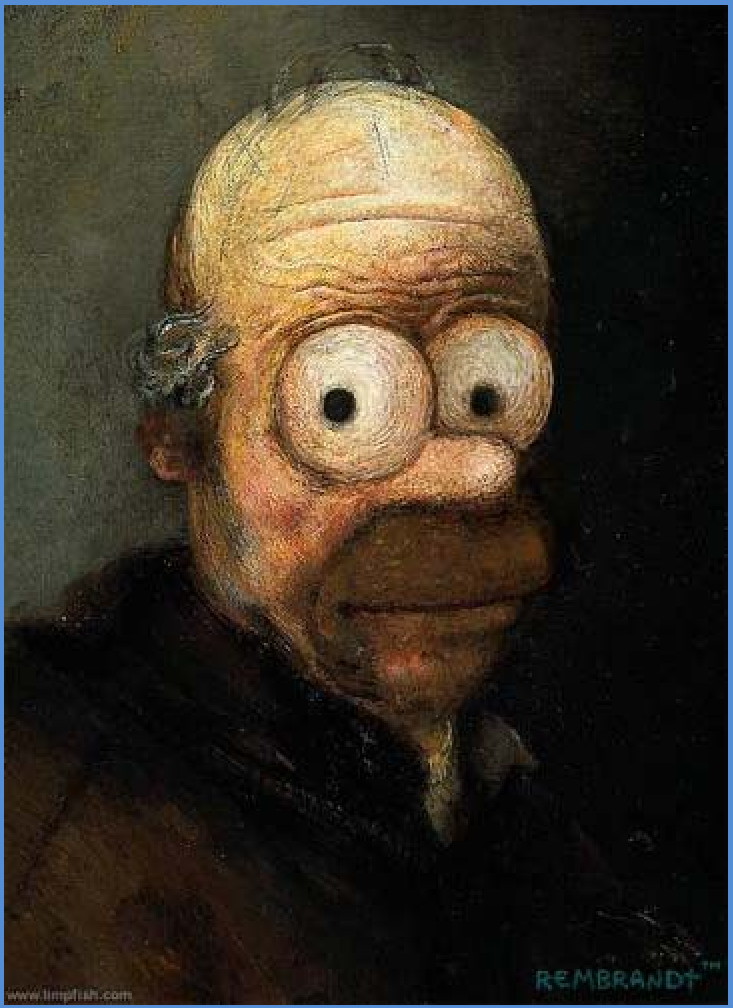
Homer's Physics



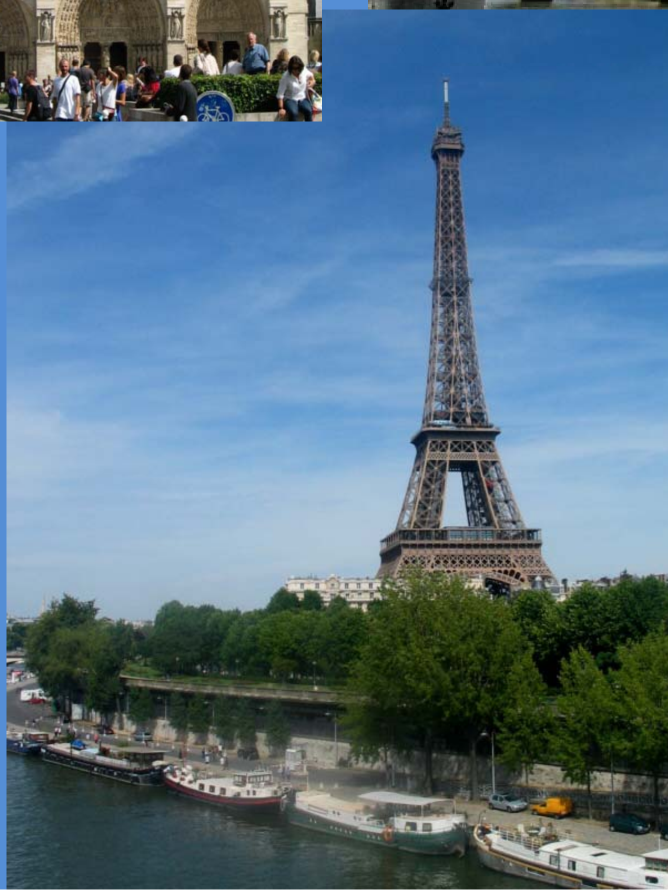
13 November, 2009

What I did on my Summer Holidays

2008/9

Vienna

Paris



Genova

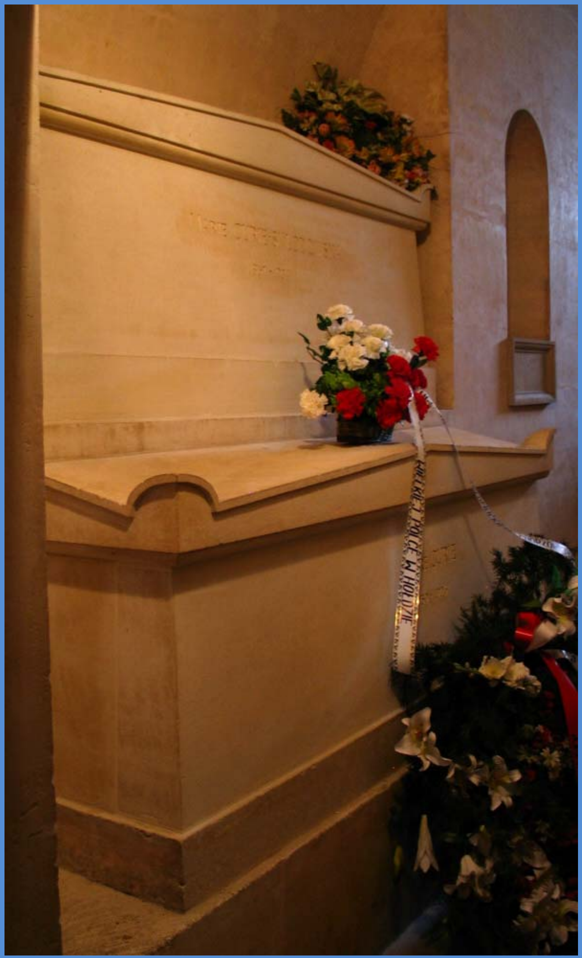
Grenoble


Winnipeg

French science facilities

Foucault’s pendulum, 1851

Early radiation workers



really

sabbatical

What I did on my ~~Summer Holidays~~

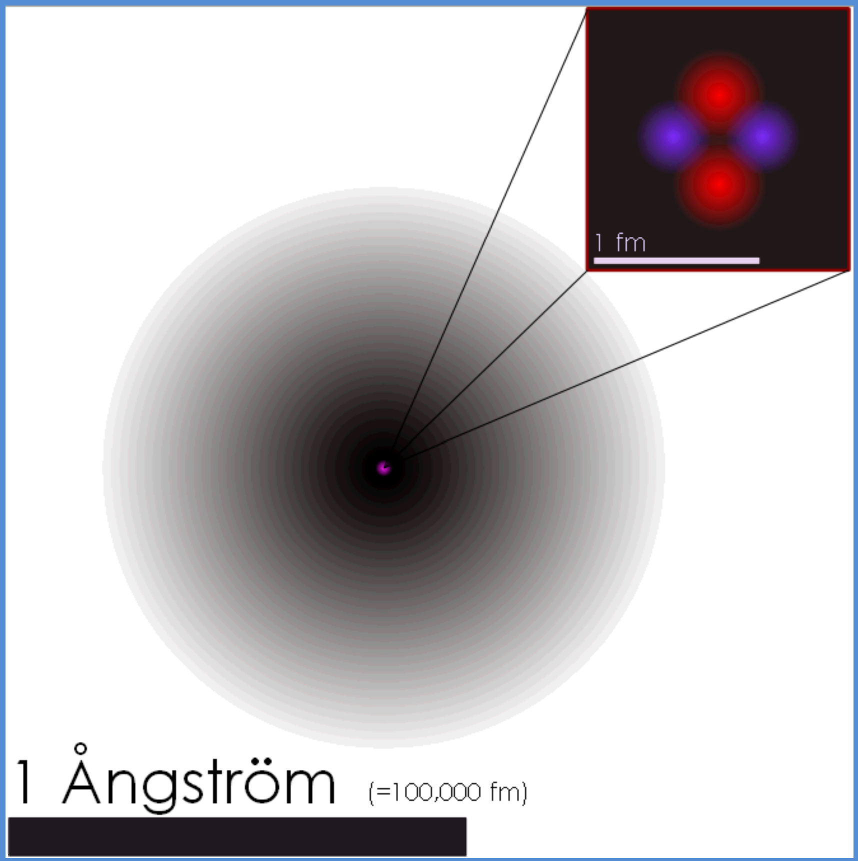
2008/9

I did a lot of neutron scattering

- What is a neutron?
- How are they made?
- What is scattering?
- Why scatter neutrons?
- Where can you scatter neutrons?
- What else are neutrons good for?

The neutron

- The neutron is one of the three basic building blocks of matter.
- It carries no charge and has the same mass as the proton.
- It is found in the nucleus with the protons.
- Neutrons, protons and electrons make up all common materials.
- With a lifetime of 15 minutes, they are rarely seen as free particles.
- They are normally made by nuclear fission in a reactor.

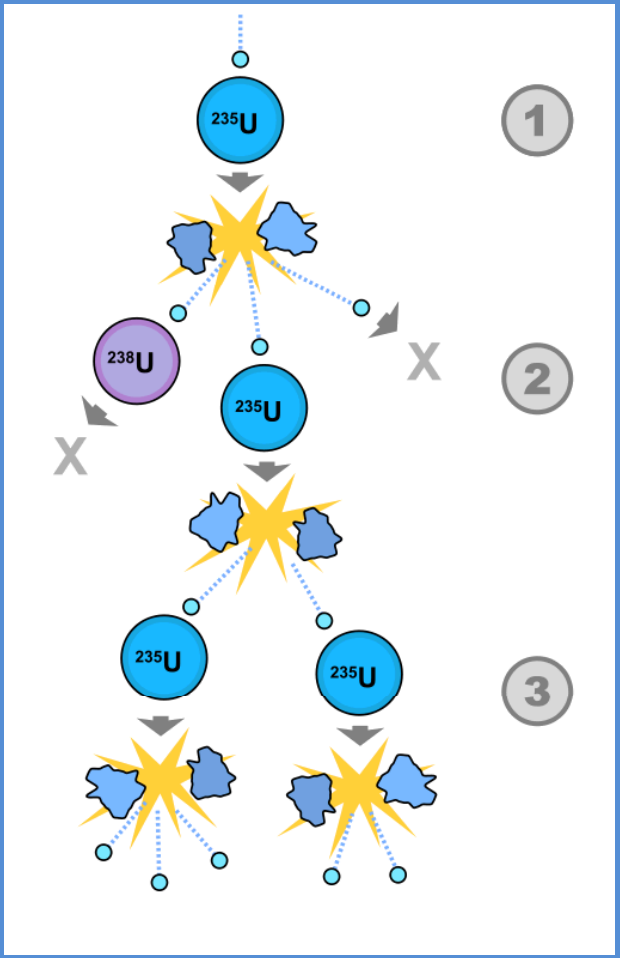


A clarification

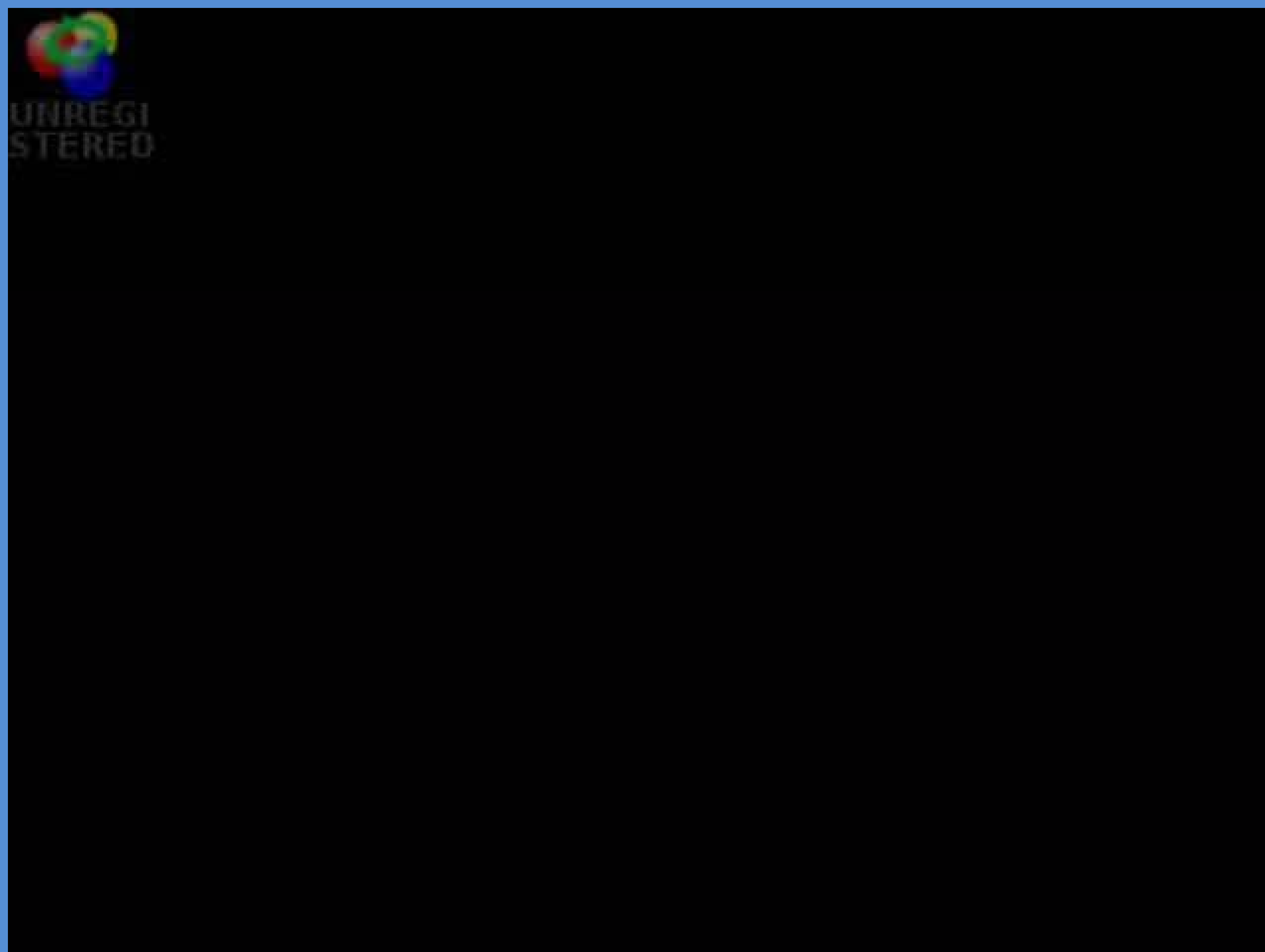
[redacted]

Nuclear fission

- A neutron hits a ^{235}Uranium nucleus, “splitting” it into two pieces.
- A few neutrons and a ***lot*** of energy is released.
- Some of the neutrons are lost, others go on to split more ^{235}U nuclei to continue the reaction.
- The process is carefully controlled to ensure that the reaction does not run away.

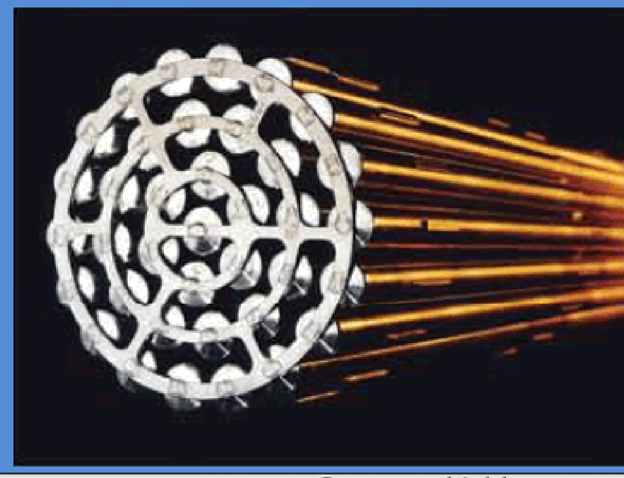


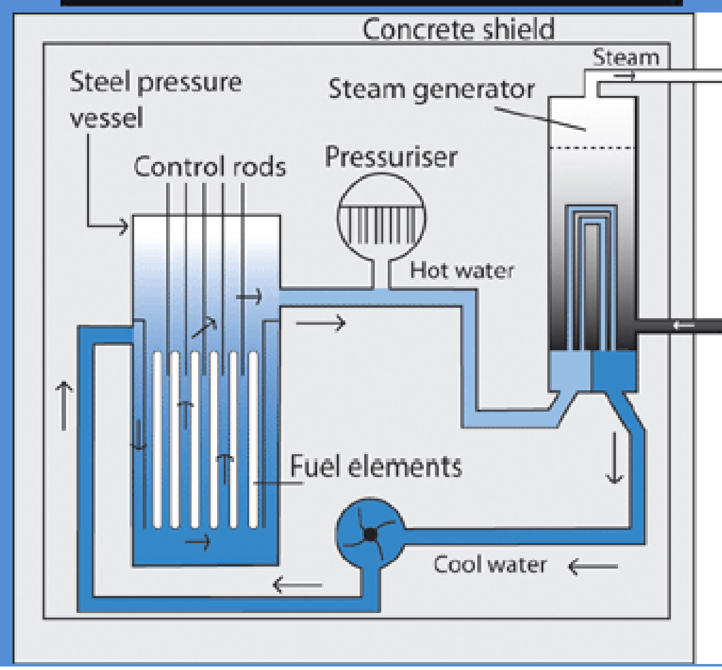
Trained professionals



Basic reactor lay-out

- The fuel is contained in sealed tubes that are cooled by flowing water
- Control rods absorb neutrons and are used to regulate the reaction
- The reactor is enclosed in a sealed vessel and the entire system is surrounded by a concrete containment building



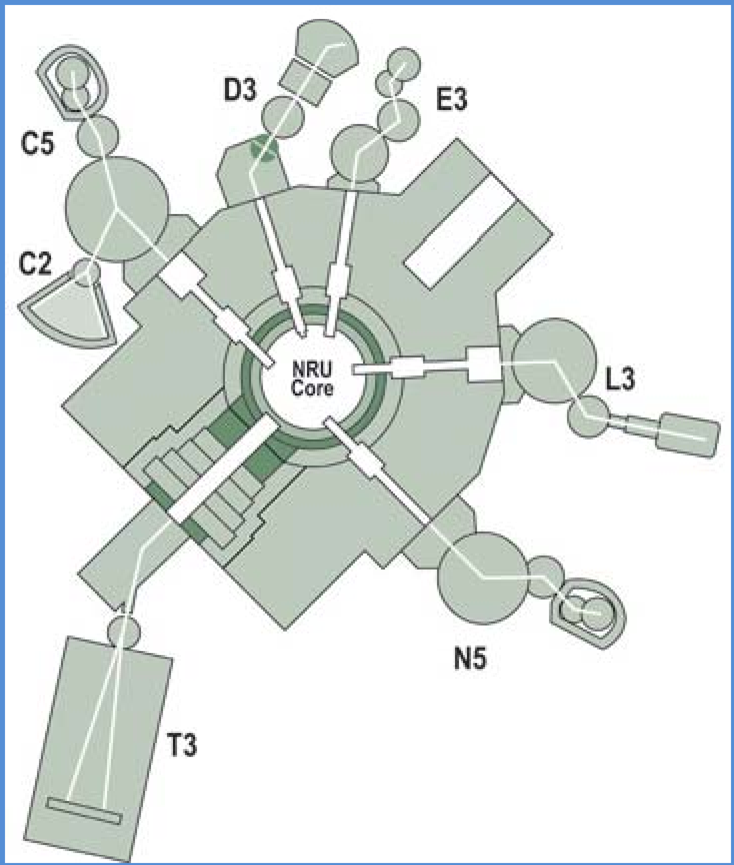


Spent fuel

- This is often referred to as “nuclear waste”, but it is in fact a valuable resource that can be re-processed and returned to the reactor to be used again.

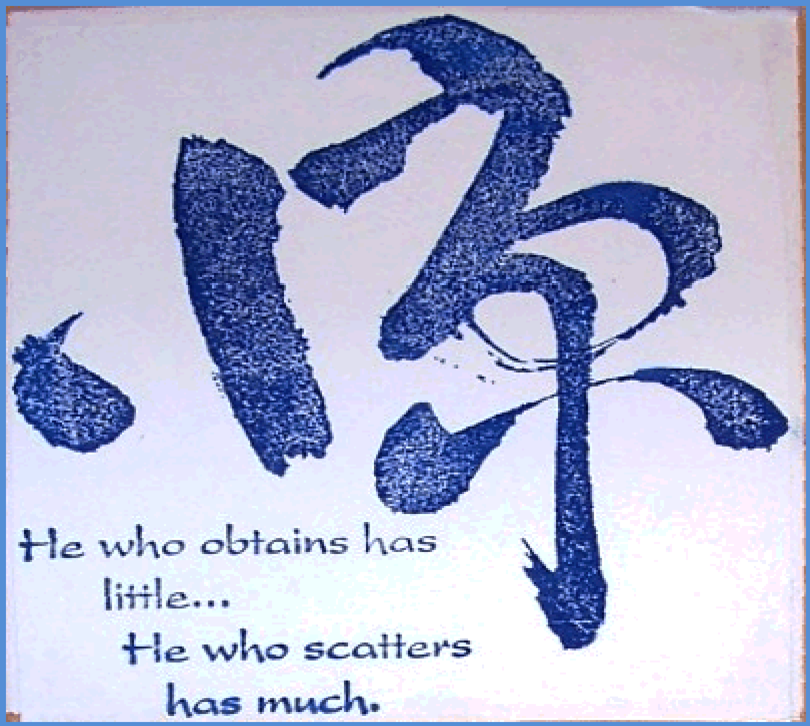
- It is, of course, treated with great care.

Neutron beams



- We get the neutron beams by poking holes through the shielding and into the core.
- The neutrons come spraying out in much the same way as air out of a punctured tyre.
- The instruments guide the beams onto the samples and then detect the scattered neutrons.

Scattering



Lao-Tzu, 6th century B.C.
Chinese moralist and mystic

- Almost everything that we know about the world around us is the result of some form of *scattering*.
- Light from the sun is reflected by objects and enters our eyes.
- Bats use sound "echoes" to see and hunt.
- Radar uses radio waves to detect aircraft
- X-rays and neutrons scatter off solids and can allow us to "see" where the atoms are.

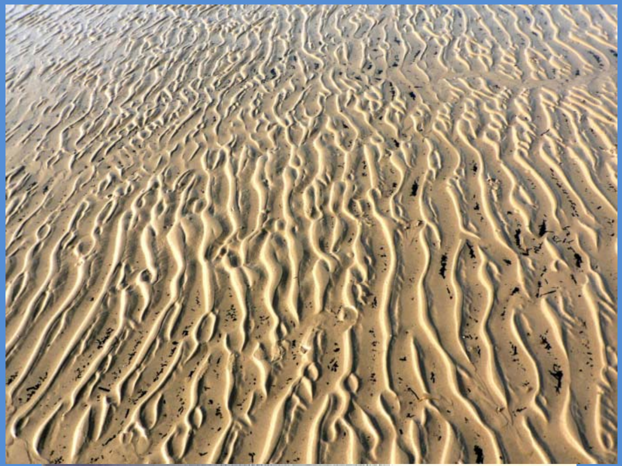
Everything behaves like waves

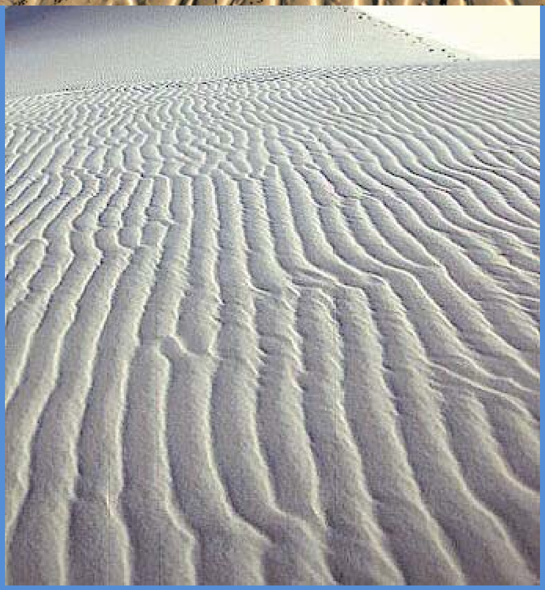
- Water, sound, light…are all examples of traveling waves
- Waves do not have to move, they don't even have to have nice shapes
- To be a wave, all they have to do is have some property that goes "up" and "down" in a regular way as we (or they) move.

Fixed waves in sand

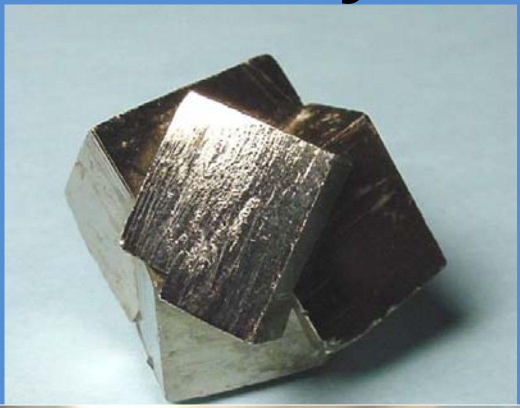
- Ripples on the surface of sand, created by water or wind action, are clearly recognisable as *waves*.

- We can generalise this idea much further.





Many minerals occur in obviously regular shapes

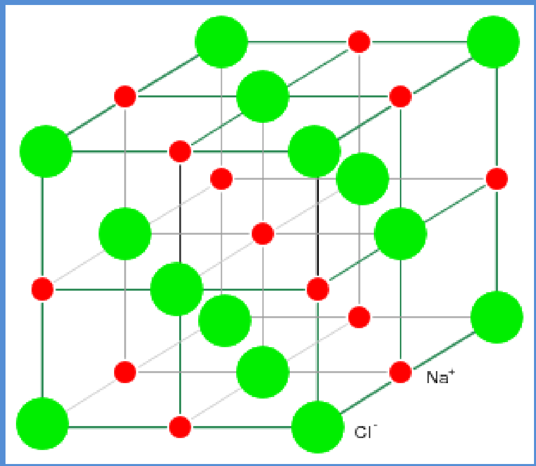


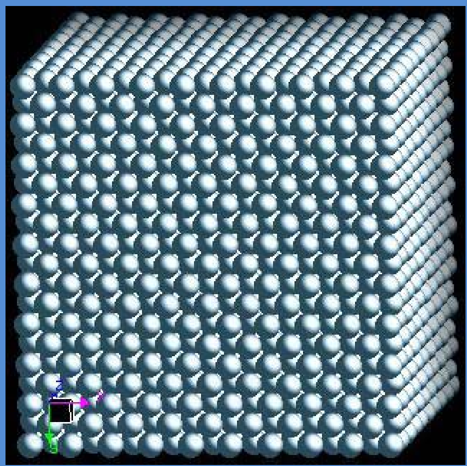




Atoms and crystals

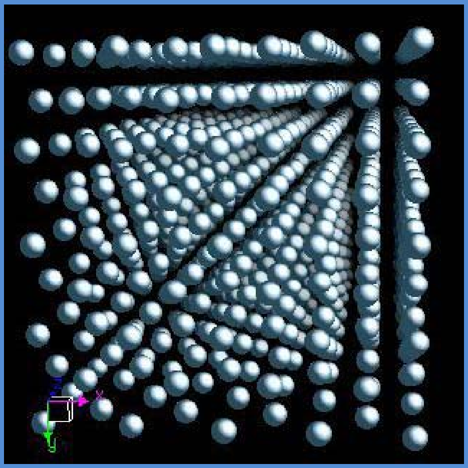
- Long before the idea of "atoms" was well established, people recognised that the shapes of mineral crystals could arise from the regular packing of simple building blocks.
- Condensed matter physics owes its origins to the discovery of x-rays as they allowed us to *measure* where the atoms are.
- Once you know where the atoms are, then all of the rest follows.

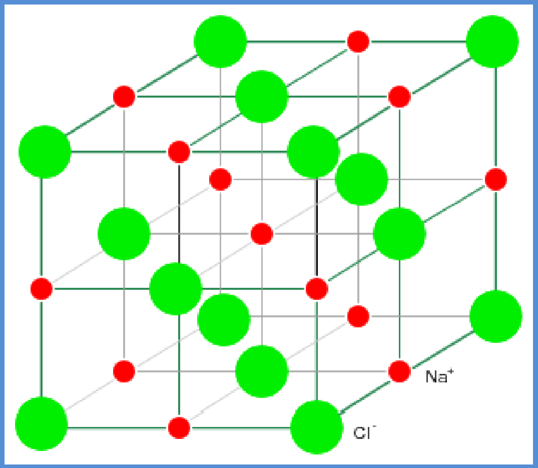




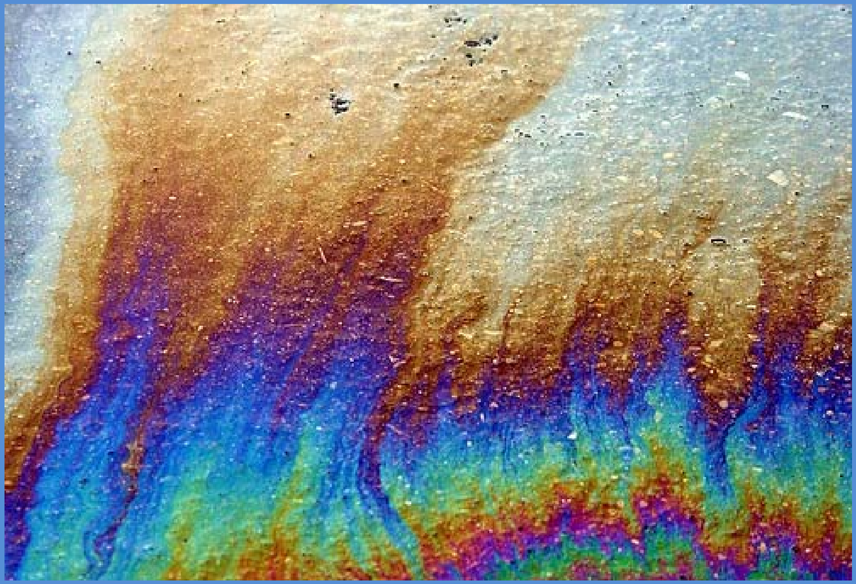
Using scattering to locate atoms

- The regular arrangement of atoms viewed from the side looks like a regular stack of layers, or sheets of atoms.
- These layers have distinct distances between them (waves?) and also angles.
- If I know all of the distances and angles, I can reconstruct the whole crystal.





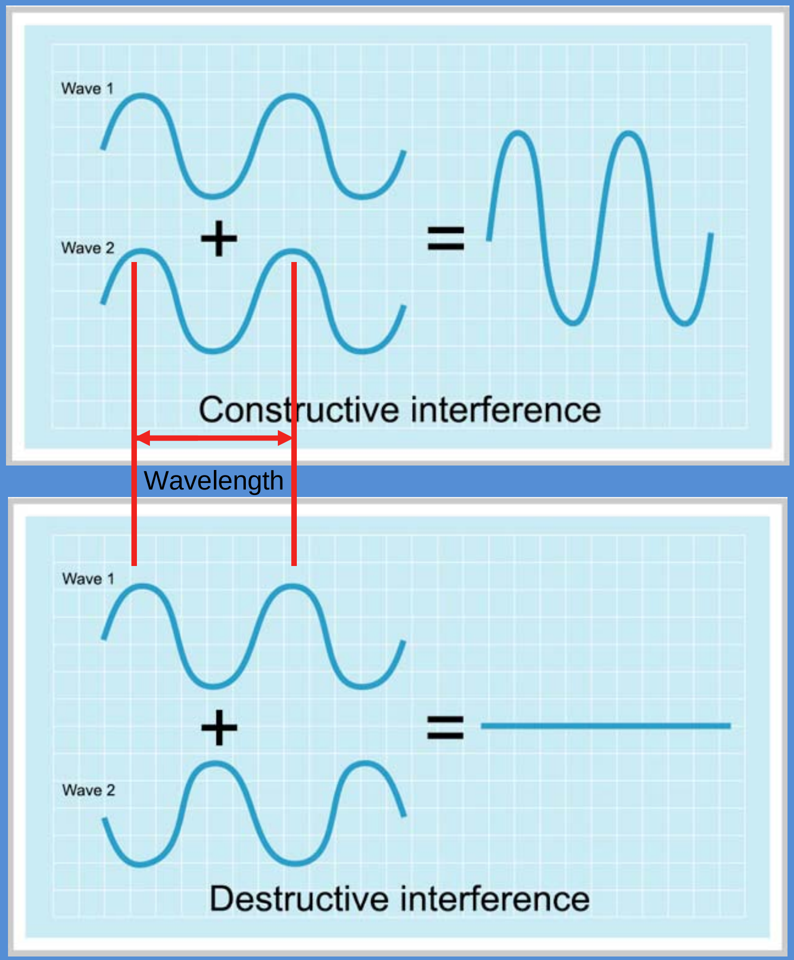
Scattering from layers – “Interference”

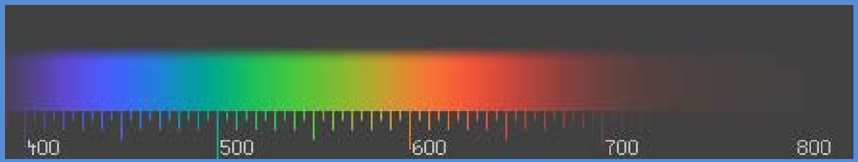


- We have all seen patches of oil on water, but where does the *colour* come from?
- It is created by light reflecting from the top surface of the oil and the oil-water boundary.

Science break…

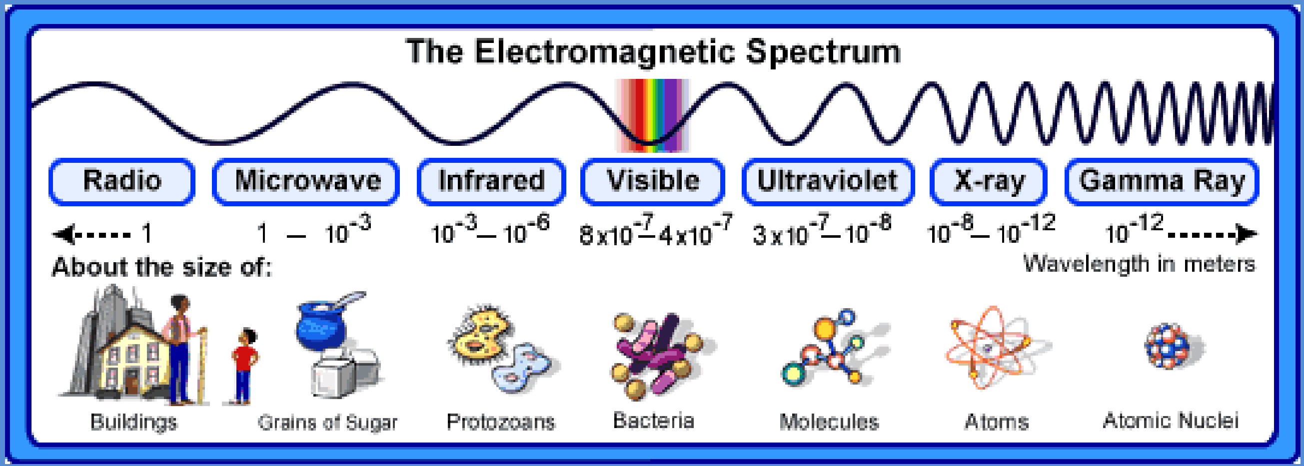
- Light is a wave
- How waves add depends on how they line up
- The wavelength for “blue” light is almost exactly half that for “red” light, so two “blue” waves will fit into the space of one “red” wave.
- That makes oil puddles look nice!





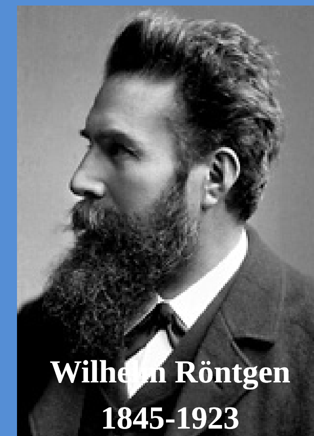
[redacted]

How can we do the same with atoms?

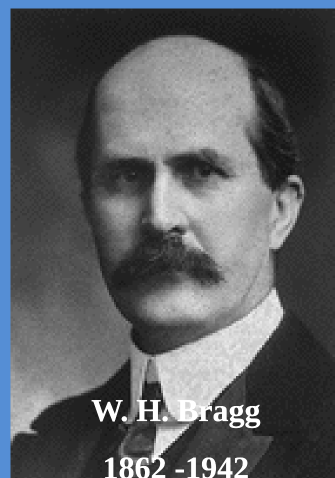


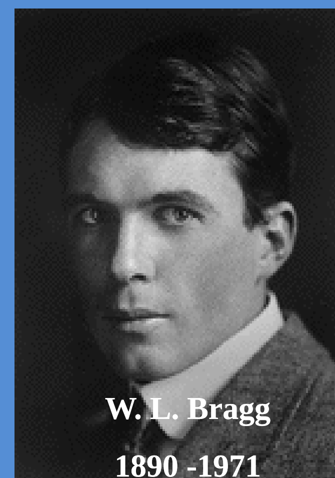
- Light is about 1000 times too "big" to see atoms
- X-rays (and by chance, neutrons) are just right!

Doing this right has led to a lot of Nobel Prizes.



Nobel Prize 1901 for "his discovery of x-rays."





Nobel Prize 1914 "for his discovery of the diffraction of X-rays by crystals"

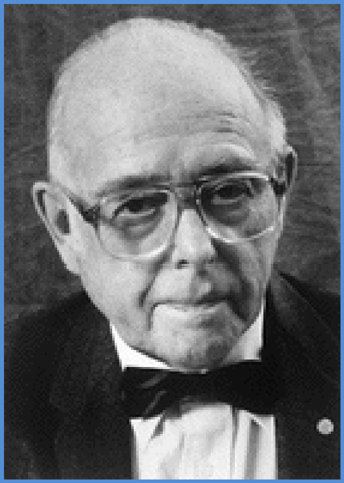
Nobel Prize 1915 "for their services in the analysis of crystal structure by means of X-rays"

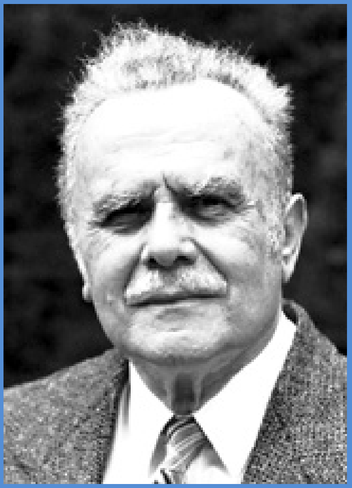
Doing it with neutrons led to more

James Chadwick
1891-1974

Nobel Prize 1935 for “the discovery of the neutron"

“for the development of the neutron diffraction technique"





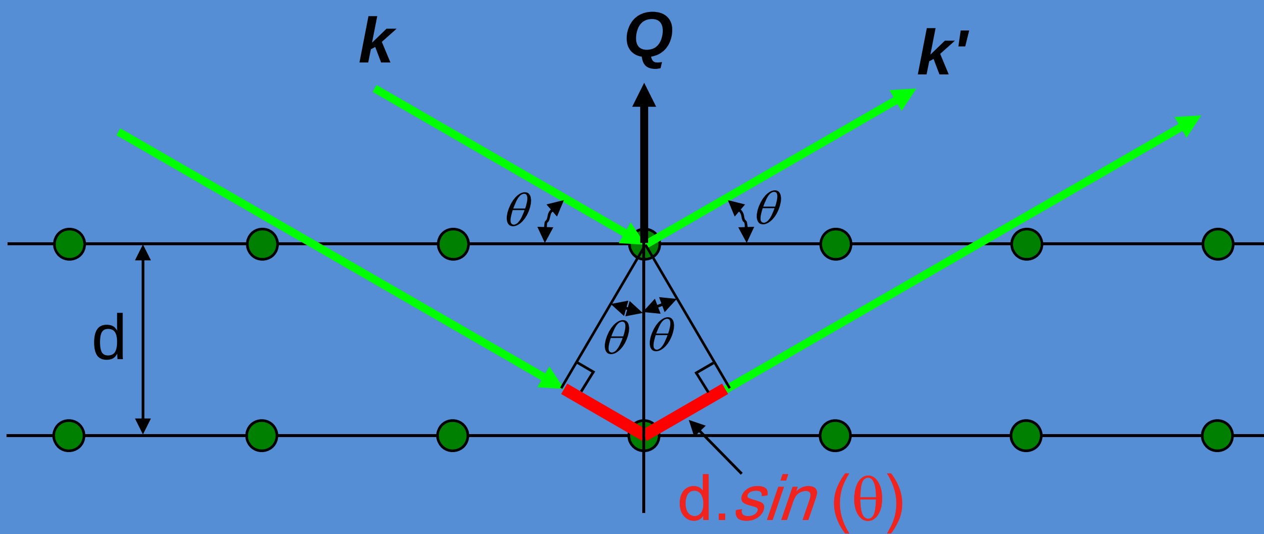
"for the development of neutron spectroscopy"

Clifford Schull
1915-2001

Bertram Brockhouse
1918-2003

Nobel Prize 1994

Diffraction Fundamentals: Bragg's Law

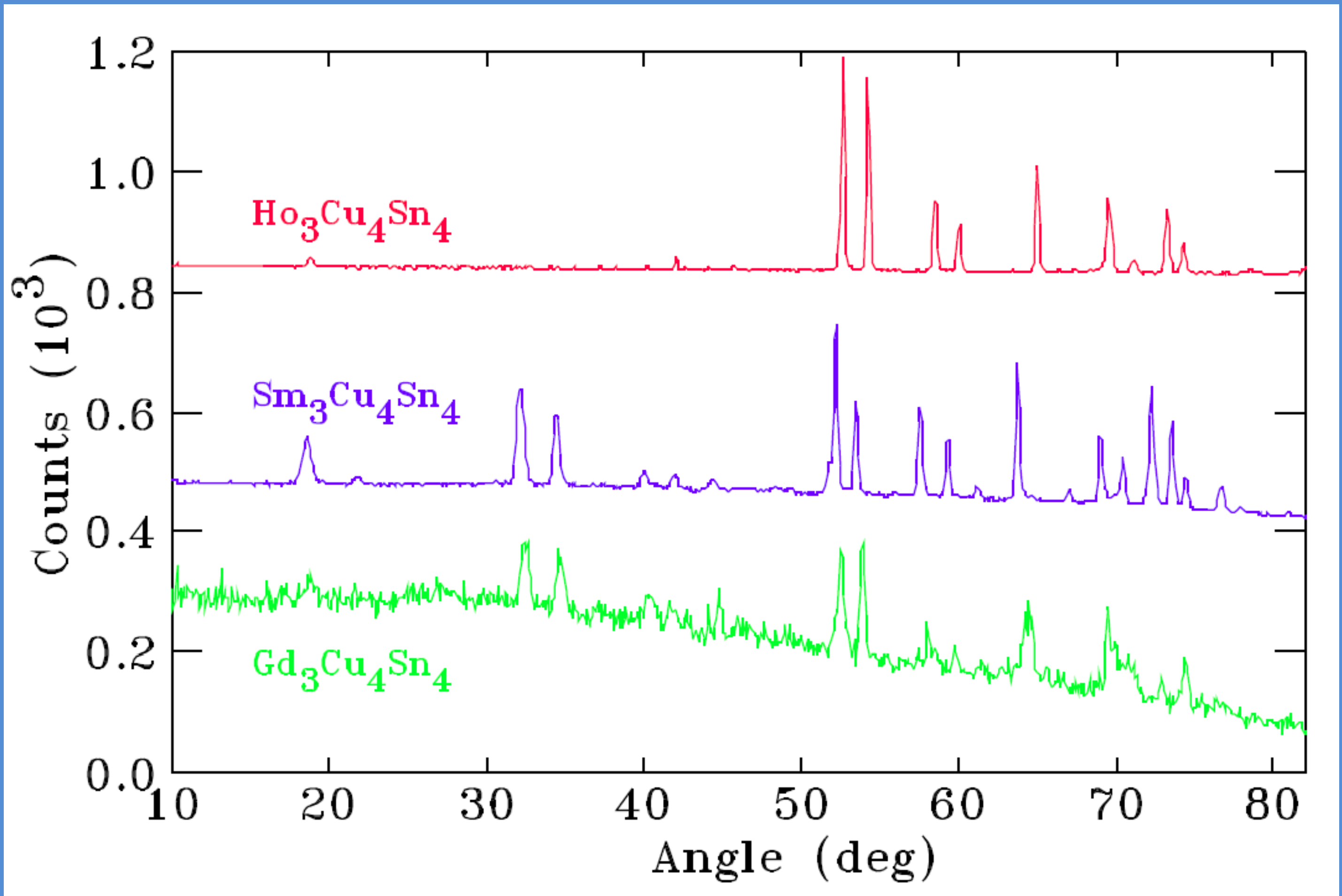


k = incoming beam
k' = scattered beam
d = layer spacing
λ = wavelength

Diffraction is an *interference* phenomenon, **NOT** a *reflection* phenomenon

Constructive interference occurs when $n\lambda = 2d \sin \theta$

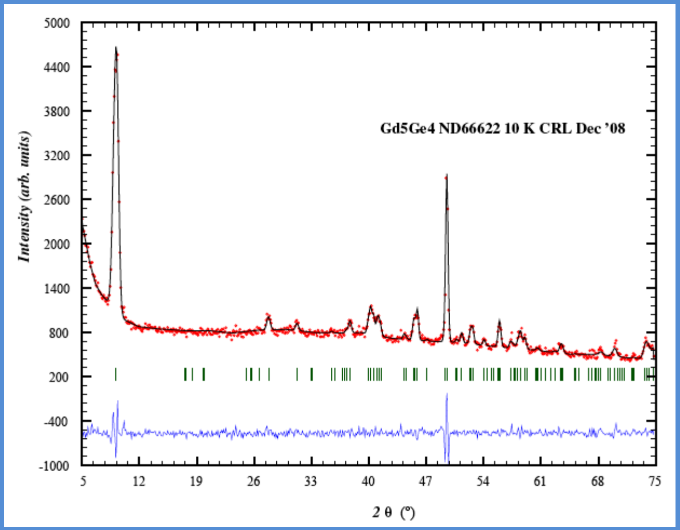
Just measure all angles and compile a list of the peak positions…

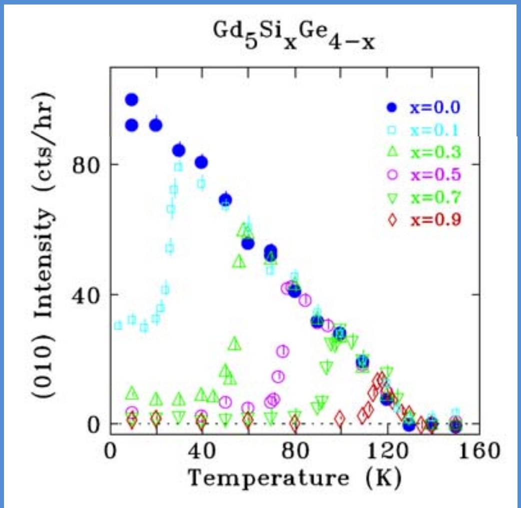


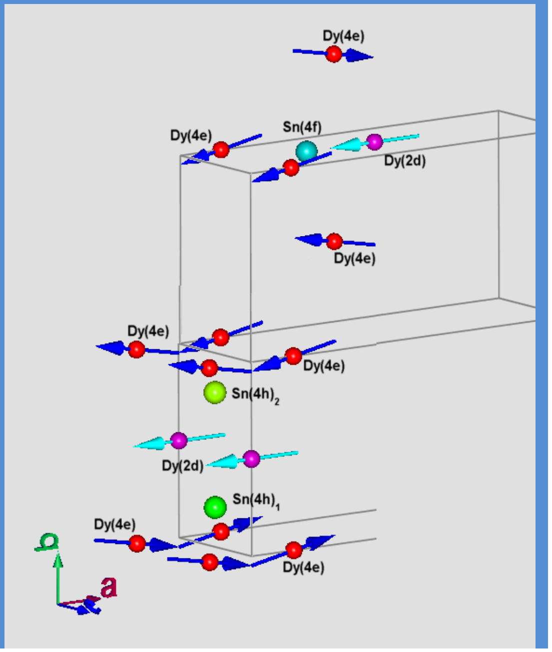
Why do I use neutrons?

- Neutrons are "magnetic", so they see not only where the atoms are, but also which way the magnetic moments on the atoms are pointing.

- This is what I do…



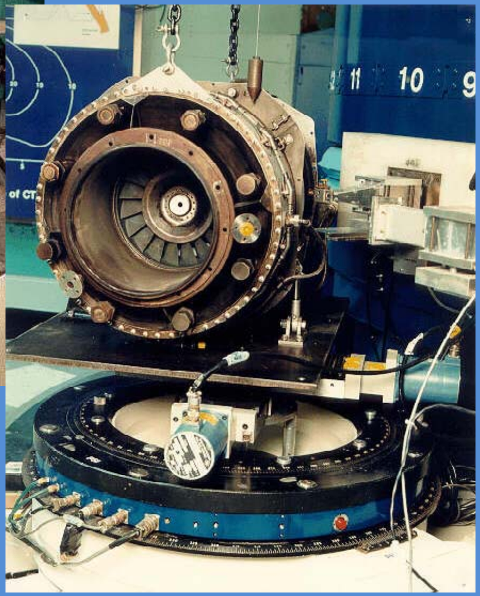




Other people use neutrons for stress mapping in engineering components

Neutron Technique Most Used by Industry

2 foot diameter steel pipe



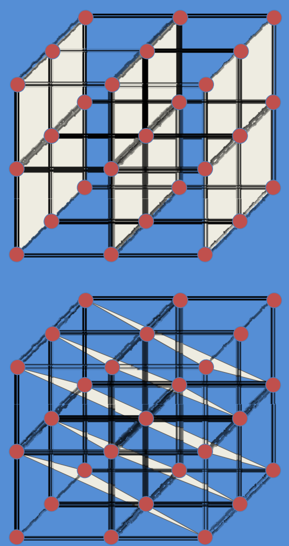
looking at internal components of a gas turbine engine

- Of most interest to the *field engineer*
- High penetration
  - Non-destructive
  - Full-scale components
  - Joints (*i.e.* welded T junction)
  - Buried interface
  - Internal components
  - Constituent stresses
  - Simulate realistic conditions
- Mature, established technique

T.M. Holden, *et al.*, Proc. 5th Canadian Conf. on NDT (1984)
A.J. Allen, *et al.*, Adv. in Physics 34 (1985), 445.
T.M. Holden, *et al.*, Met. Trans. 19A (1988) 2207.
ISO/TS 21432 (2005), Non-destructive testing -- *Standard test method for determining residual stresses by neutron diffraction.*

ANDI

Measuring Strain by Diffraction



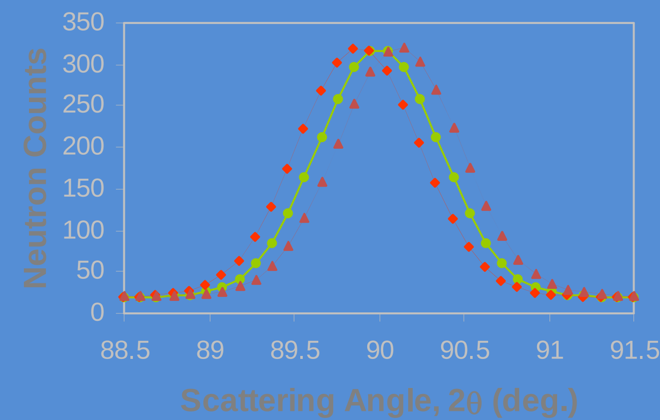
$$\varepsilon \equiv \frac{d - d_0}{d_0}$$

$$\lambda = 2d \sin(\theta)$$

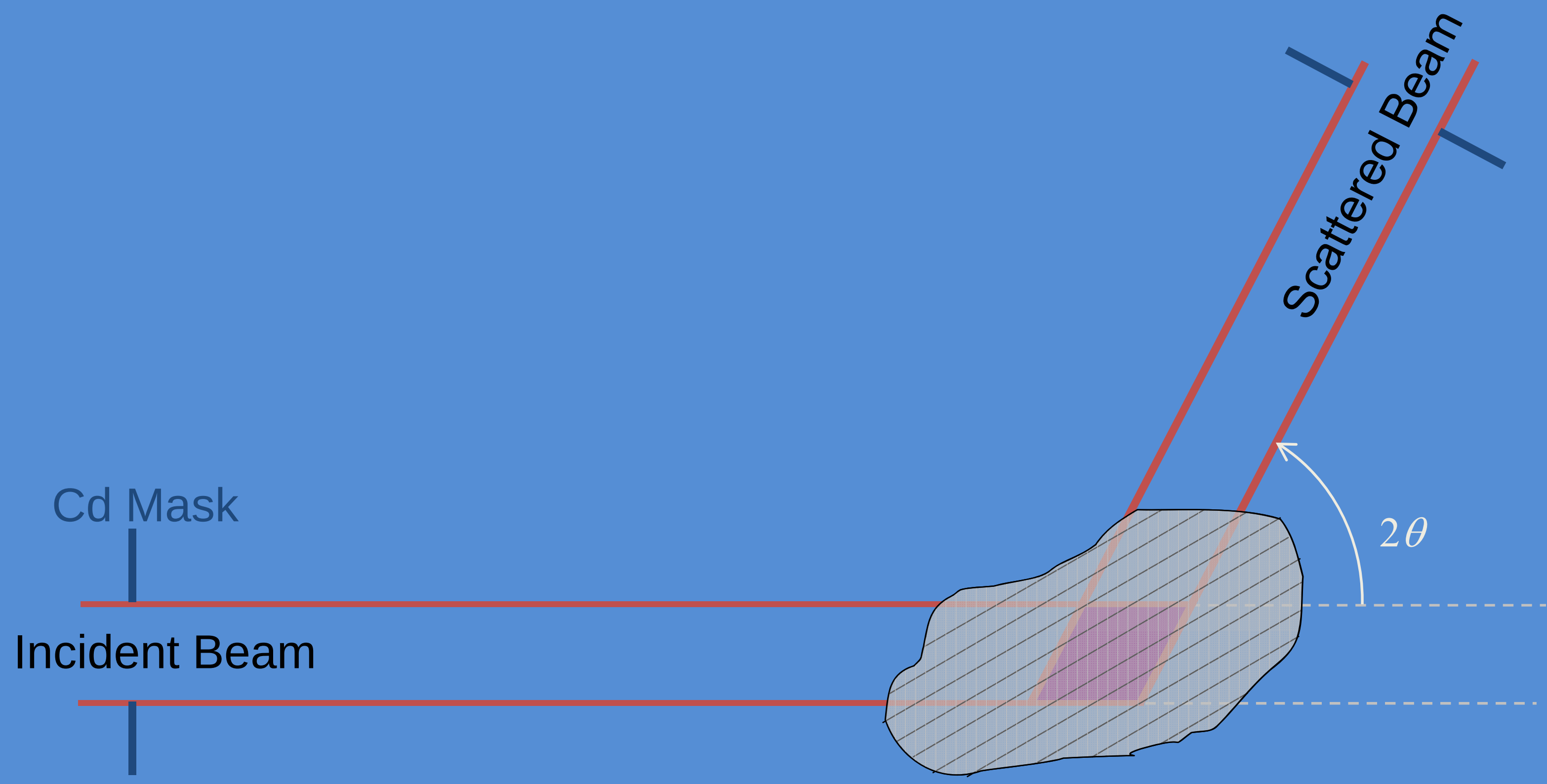
Stress-free (d_0)

TENSION (+)

COMPRESSION (–)



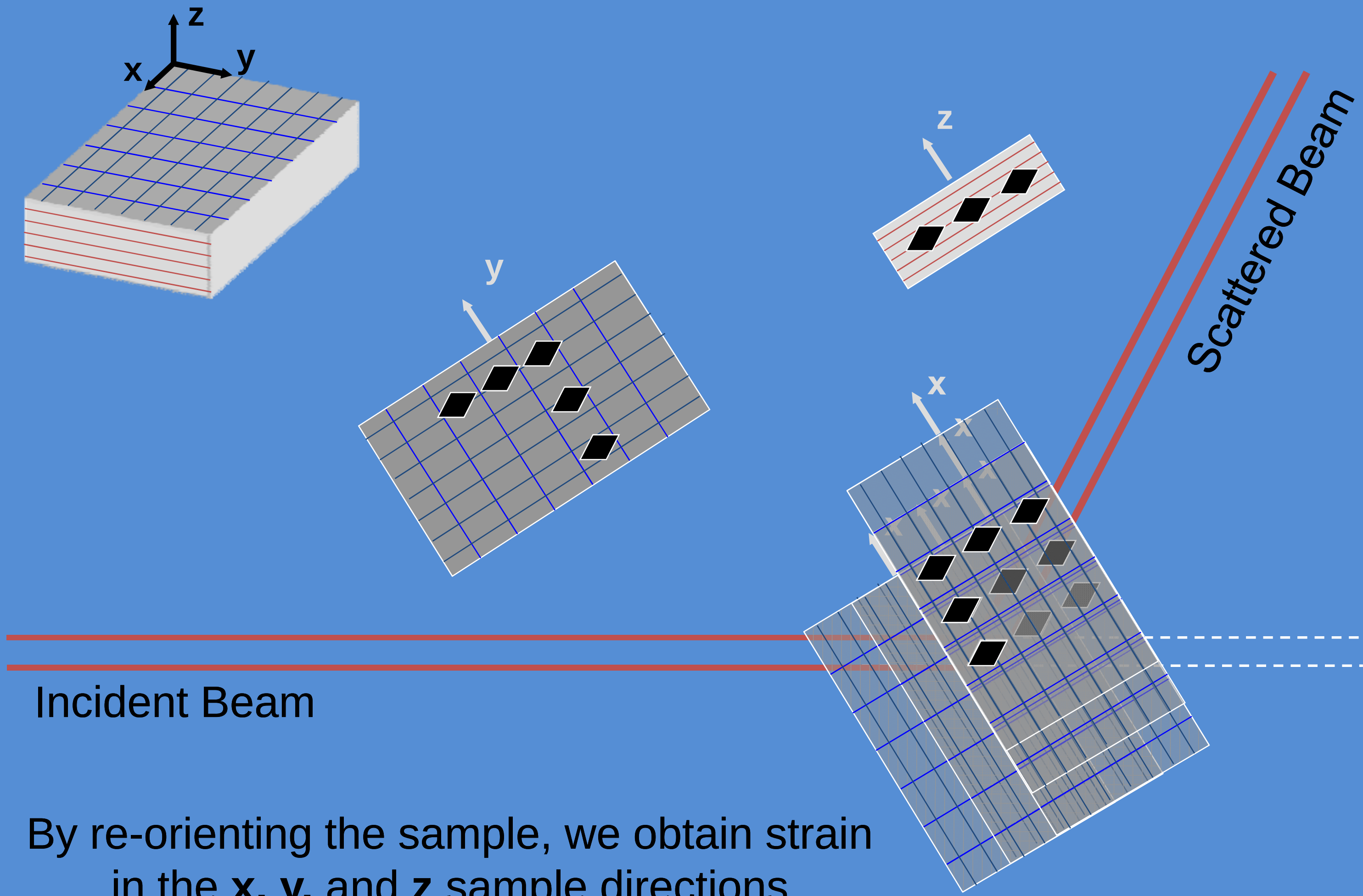
Mapping Stress at Depth



Get strain data only
from material inside
the Sampling Volume

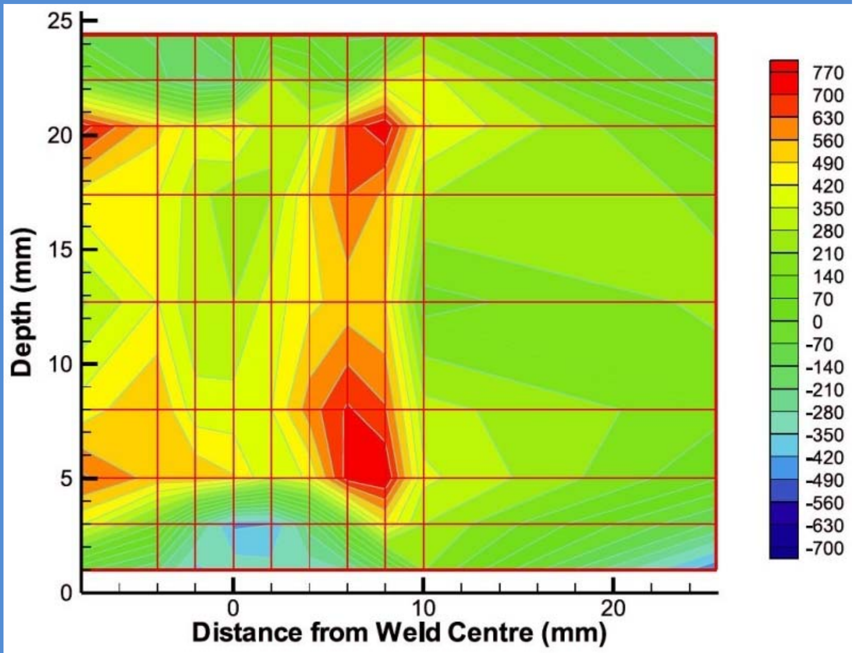
Mapping Stress at Depth

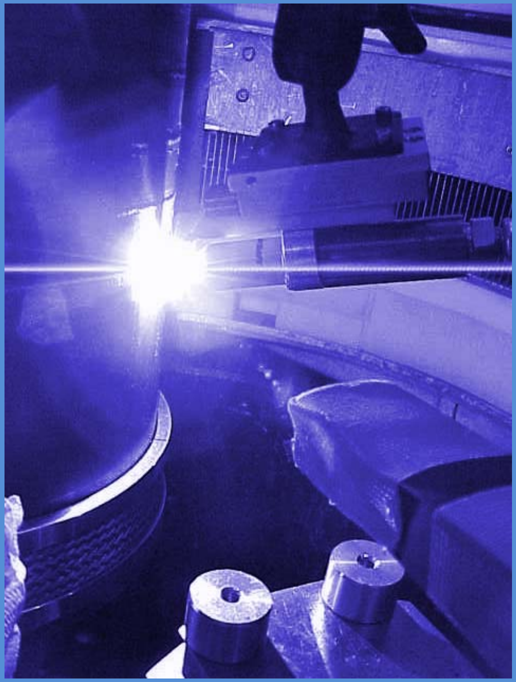
Usually we need 3 components



By re-orienting the sample, we obtain strain in the **x, y,** and **z** sample directions

The final result is a map of the stresses *inside* the component





Neutrons can also be used to study the welding process as it happens

These techniques were *invented* and developed by scientists working at Chalk River Laboratories

[redacted]

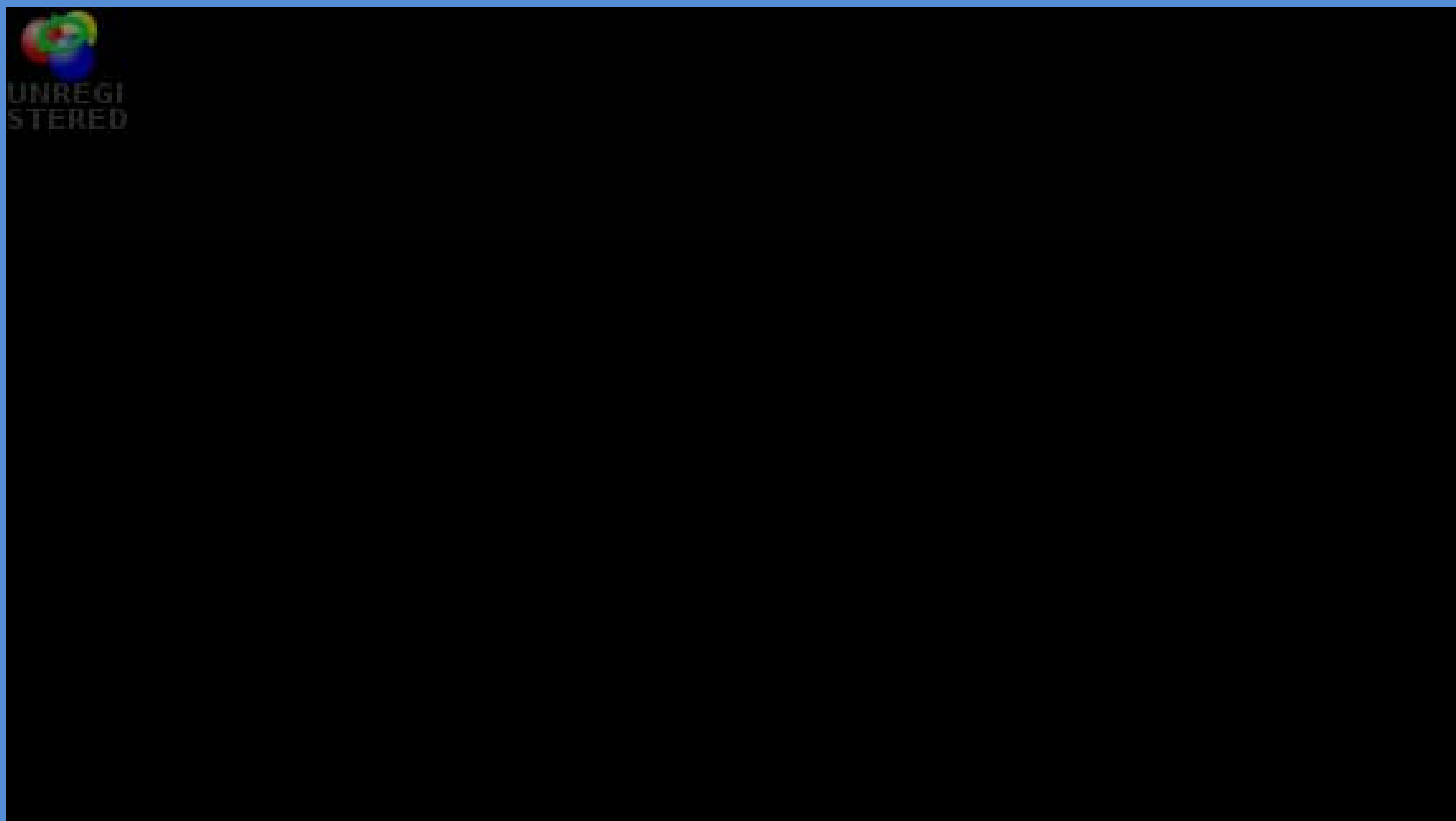
Where do the neutrons come from?

- I mainly use the NRU reactor at Chalk River.

- I was running when it sprang a leak and was shut down.

What went wrong?

The real problem is that NRU is 52 years old and was being run into the ground



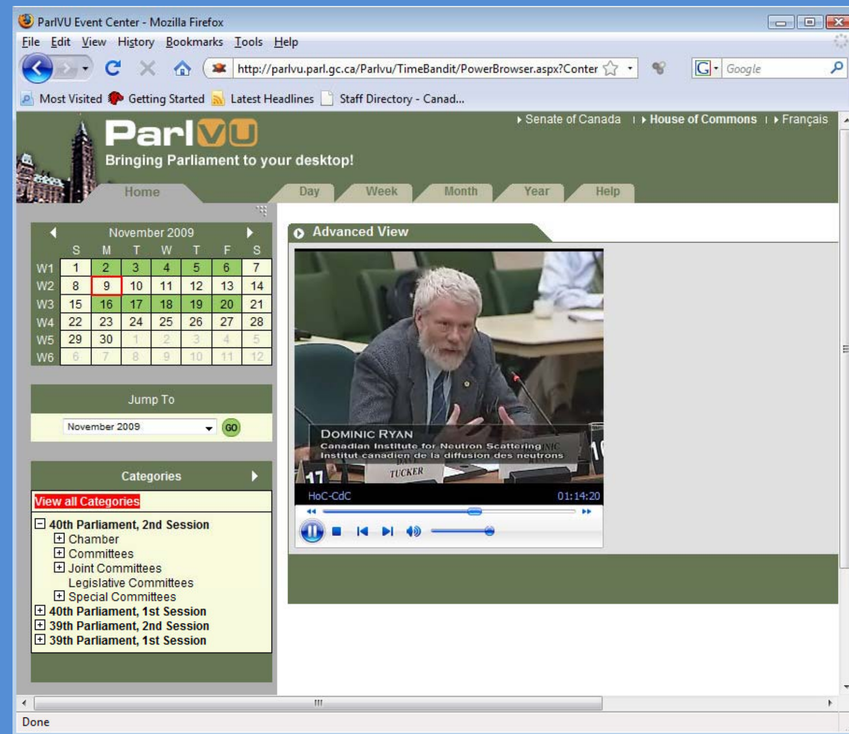
I was forced to move my experiments

OPAL, Lucas Heights
(near Sydney, Australia)

ILL, Grenoble
in the French Alps

Australia is no joke!

What is happening now?

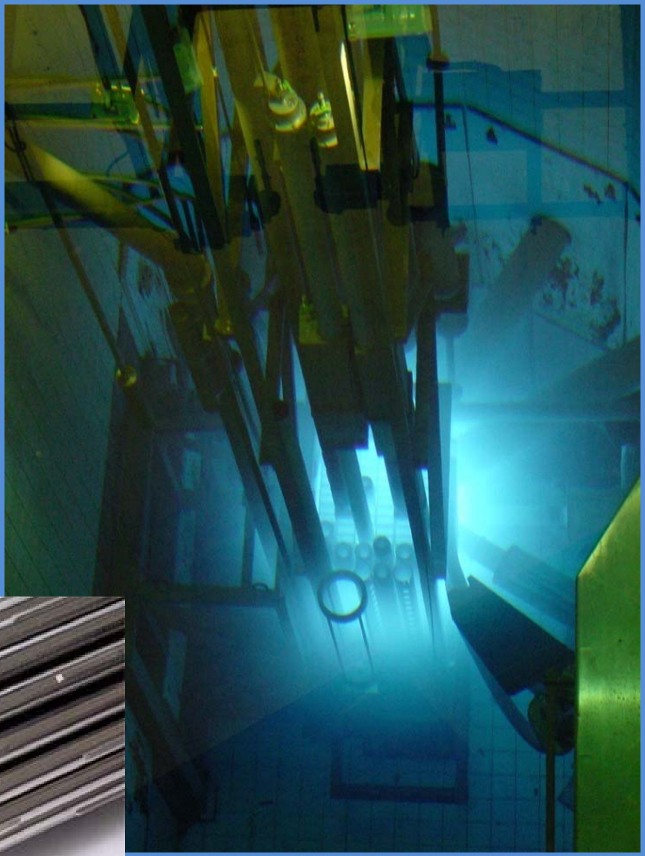


I suddenly start appearing on TV, going to hearings, making presentations, going to exciting places like Ottawa, Toronto (twice), Saskatoon...

We try to get a new reactor built!

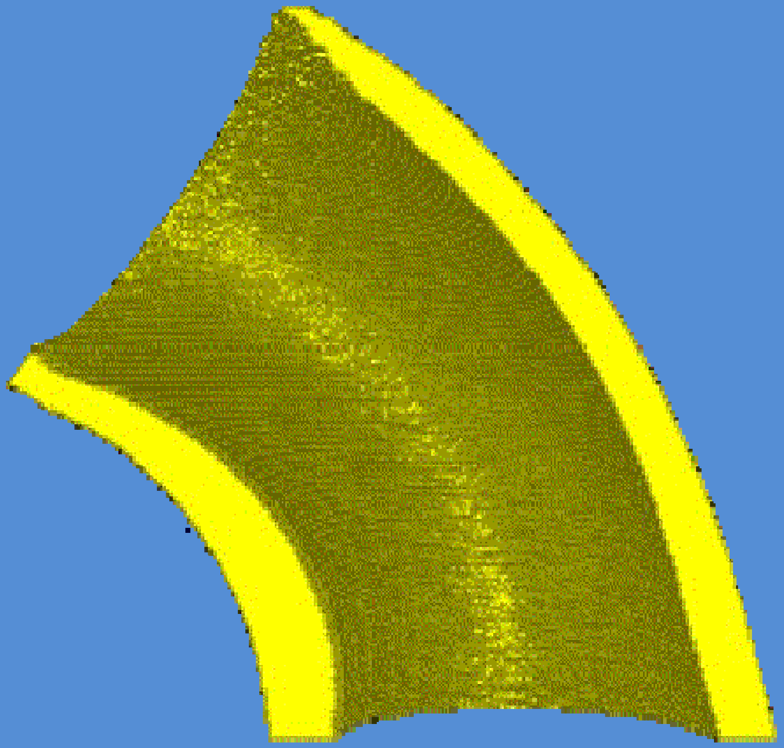
A research reactor does more than provide a place for me to play

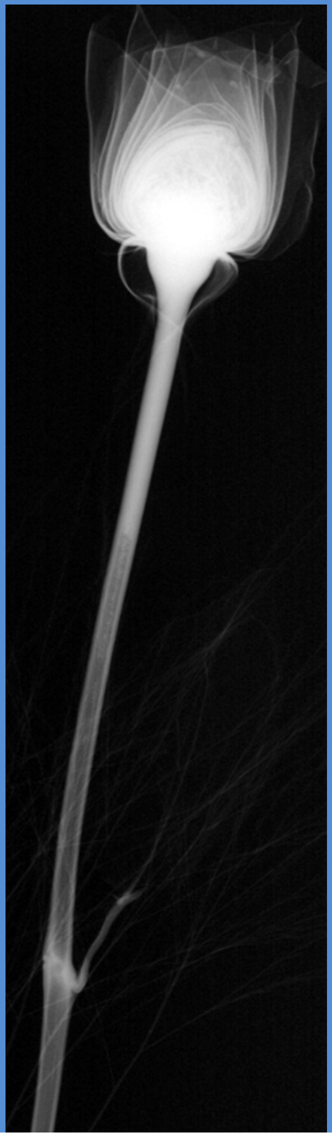
- Fundamental research
- Reactor research
- Engineering research
- Medical isotopes



Engineering research: Neutron radiography and tomography

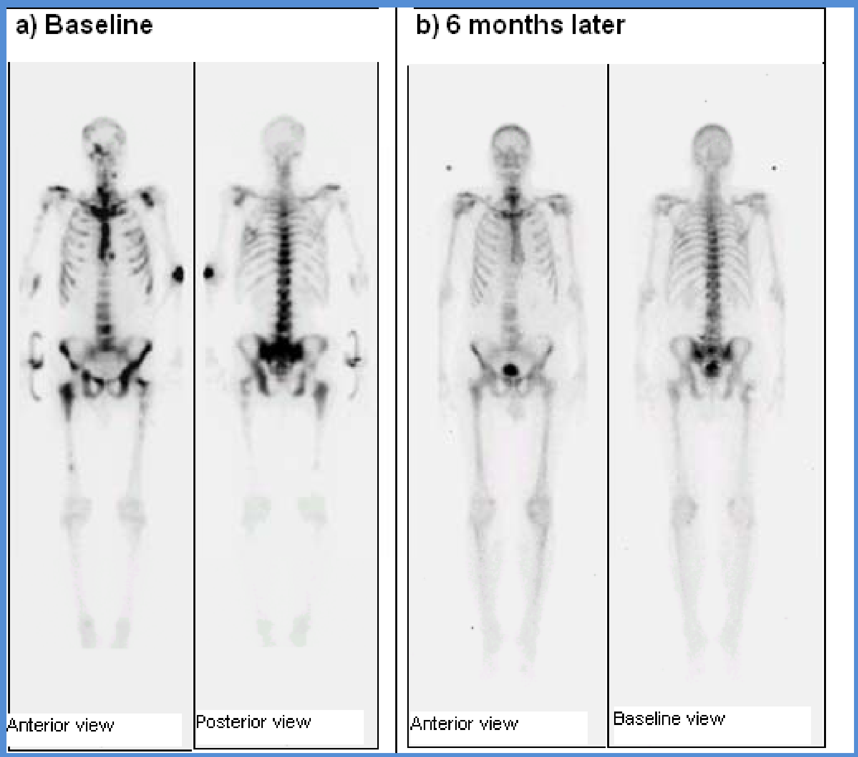
Internal structure of a bent pipe

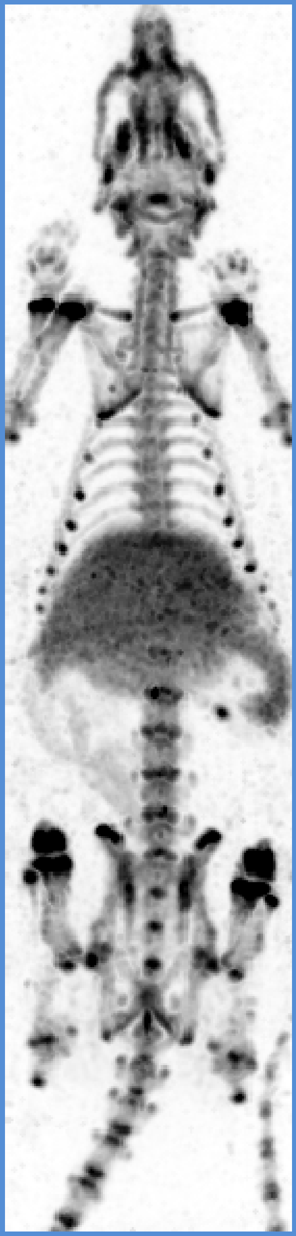




Delicate biological materials

Medical isotopes





^{99}Mo for Technetium generators

^{60}Co for cancer treatments

^{131}I for thyroid problems

Impacts

- Development of next-generation nuclear power reactors
- Engineering research in support of Canadian industry
- Fundamental science (toys for me!)
- Medical isotopes

I bet that *everyone* here, knows at least one person who has benefitted *directly* from medical isotopes made in NRU.

Price Tag?

$1,000,000,000

(or about $1/Canadian/year)

Please…