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From Discovery to Innovation...

Applied Neutron Diffraction for Industry

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NRC - Canadian Neutron Beam Centre

Neutrons for Engineering Diffraction: Opportunities for Industry

Oak Ridge April 19, 2007

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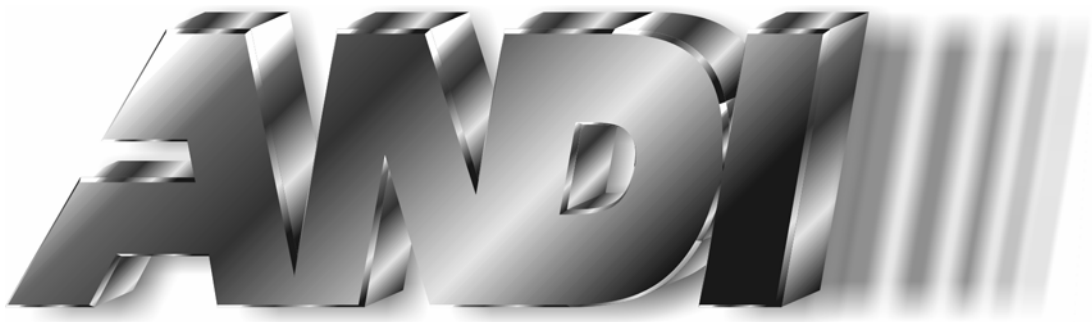
Applied Neutron Diffraction for Industry



- Beginning in mid-1980's, the Chalk River neutron beam group (government laboratory) undertook to apply neutron scattering methods to problems of industry.

- First demonstrations of residual stress mapping [1,2] and intergranular stress effects [3] in engineering materials and components

ANDI Framework

Knowledge is needed to reduce costs, open markets and grow

- Safety-reliability / sustainability of business
- Failure investigation / protecting business
- Optimized materials and manufacturing / surpassing competitors
- Address regulatory requirements / expanding business

Translations

"Experiment" → "Test / Service"
"User or Collaborator" → "Client"
"Research Proposal" → "Contract"

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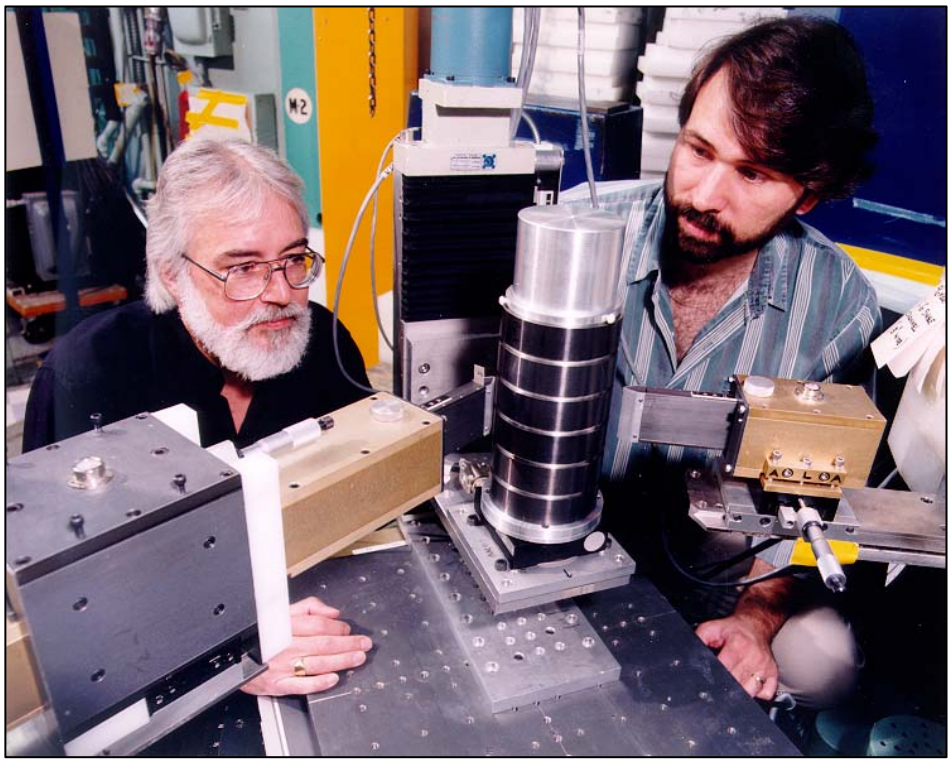
Nuclear sector

Qualifying a new supplier



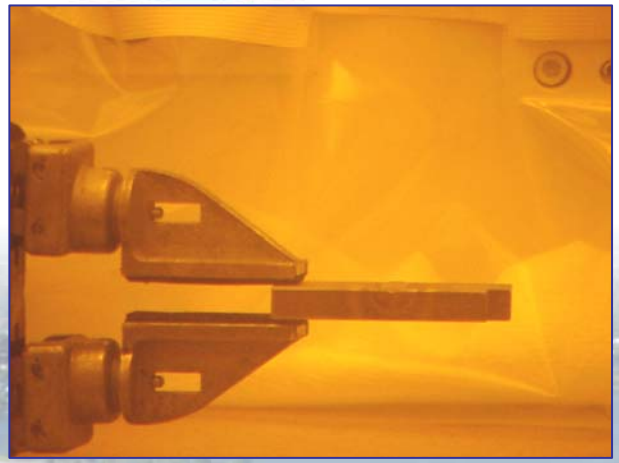
Neutron diffraction surveys bulk material rapidly and gives detailed crystallographic information vs. circumferential position in six specimens.

Would we be compromising reliability of our product if we switch to components made by a different supplier?

–Homogeneity
–Crystallographic texture
–Residual stresses
–Minority phases

Nuclear sector

Plant life extension



Handling an active specimen

Stress-mapping in 200Sv/h specimen

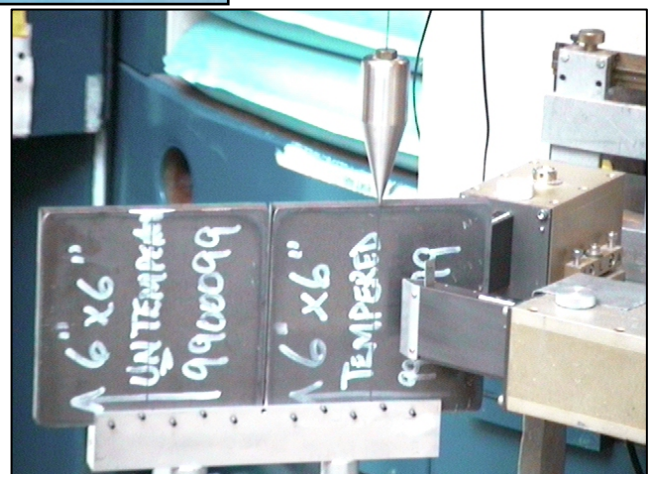
After fast-neutron irradiation, weld stresses may be relieved (?), so the probability of stress-corrosion cracking is lower…

Reliable knowledge is needed to make decisions on continued fitness-for-service.

Manufacturing sector
Opening new markets

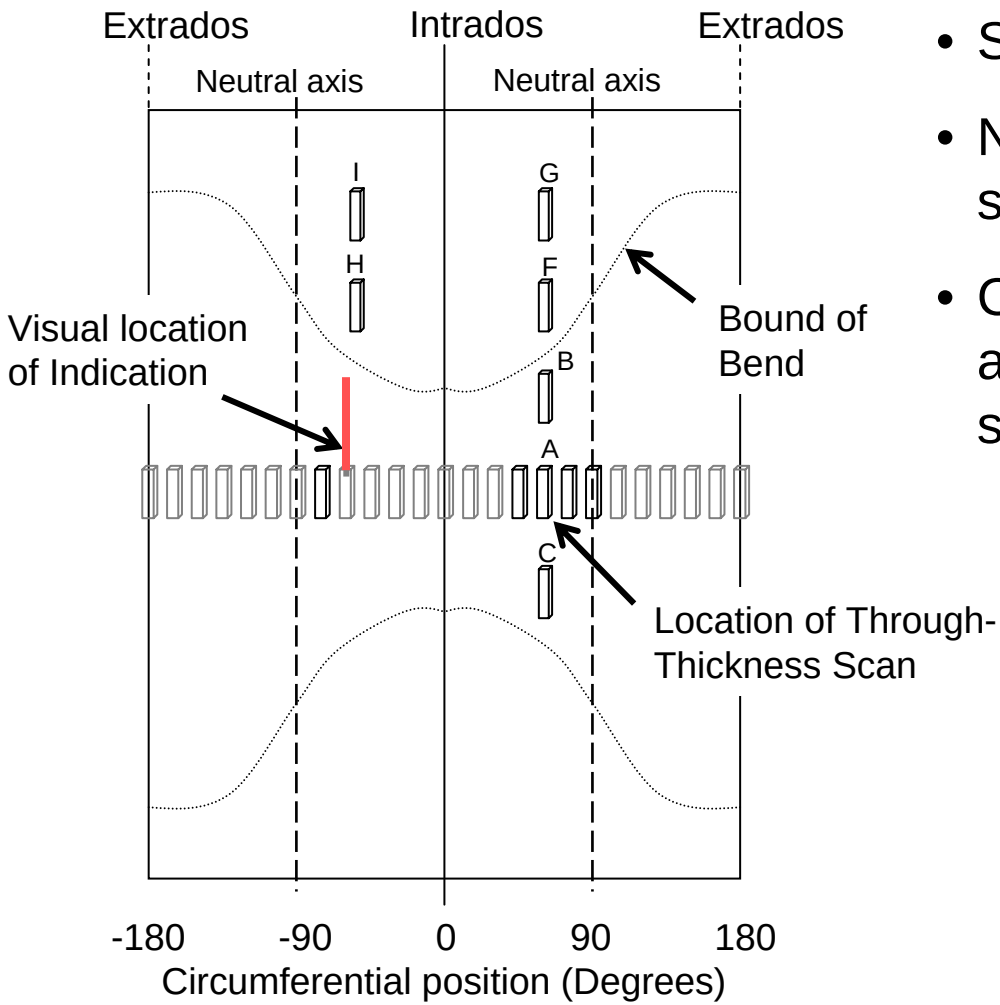
Light-weight pressure cylinder for natural gas.

Tougher bolts (TRIP steel)

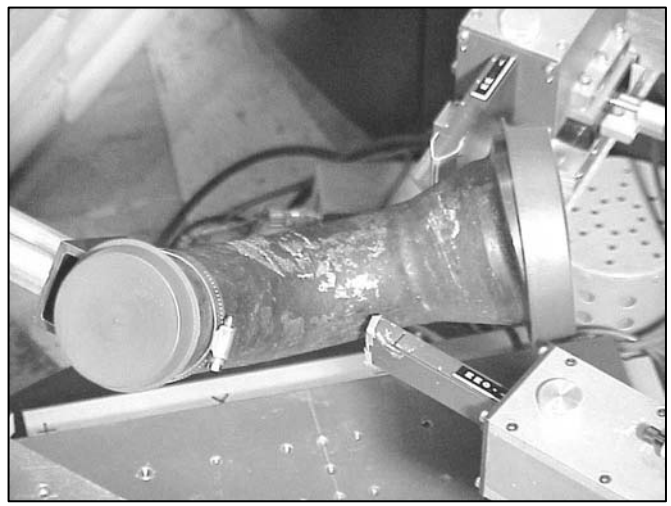


"Based on this evidence, the Steel Structures Subcommittee of the Canadian Standards Association recommended temper-levelled plate be approved for use."

Failure analysis

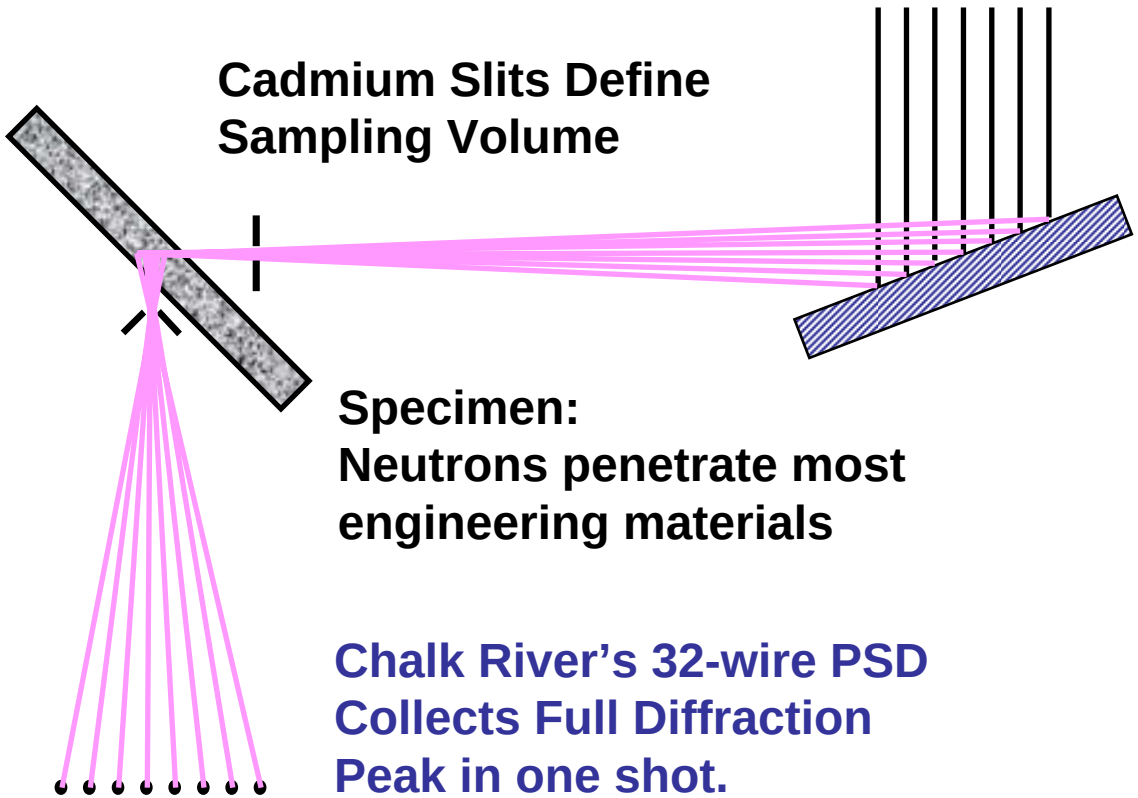


- Shutdown costs ~ $1M/day
- Non-destructive neutron stress scanning is 2nd step of investigation.
- Client receives residual stress data at key locations 16 hours after specimen arrives on site (9:00 pm)



Diffraction-based scanning

Beyond imaging



Cadmium Slits Define
Sampling Volume

Thermal
Neutron Beam
from NRU Reactor

Ge crystal monochromator with 0.2° mosaic spread and beam-compressing geometry

Specimen:
Neutrons penetrate most engineering materials

Chalk River's 32-wire PSD Collects Full Diffraction Peak in one shot.

Low-background shield.

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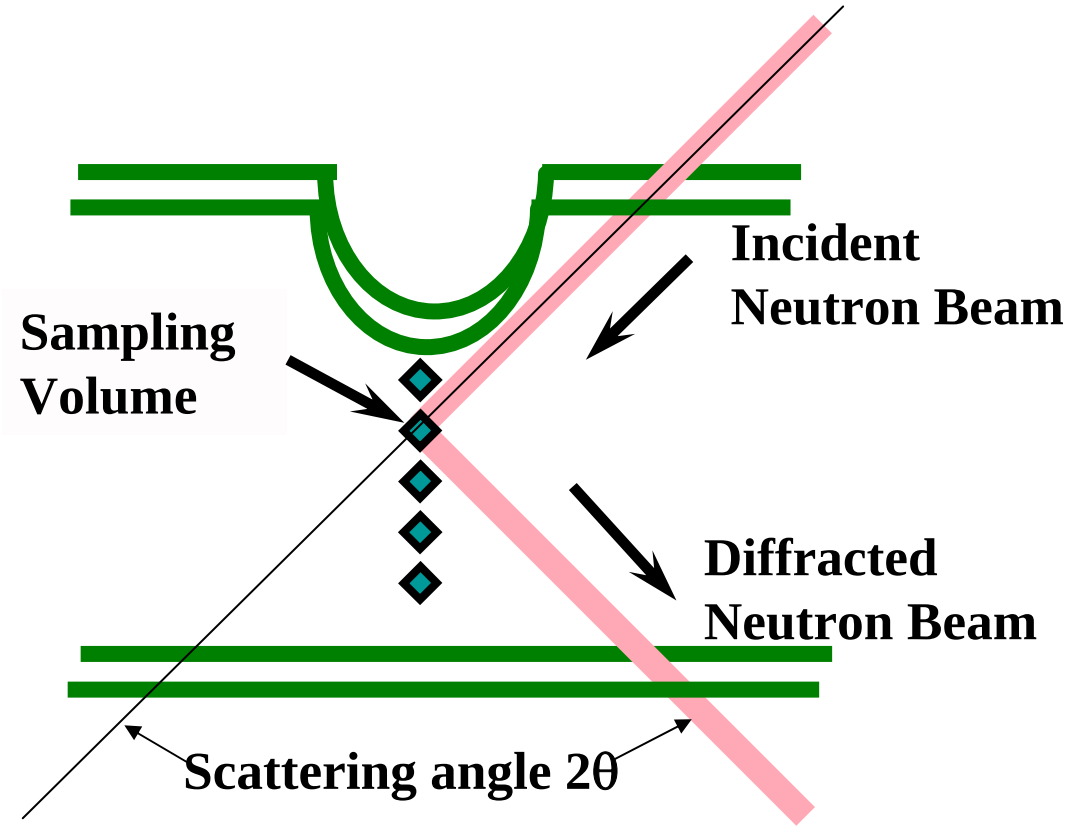
Non-destructive scans

Sampling volume / pixel



Spatial resolution ~ 1 mm^3 is the intensity limit at a medium-flux neutron source, for untextured, fine-grained material.

Time-averaged monochromatic flux at specimen ~ 2 x 10^6 /cm^2/s

Crystal lattice strain
$\sin(\theta_{ref})/\sin(\theta) - 1$

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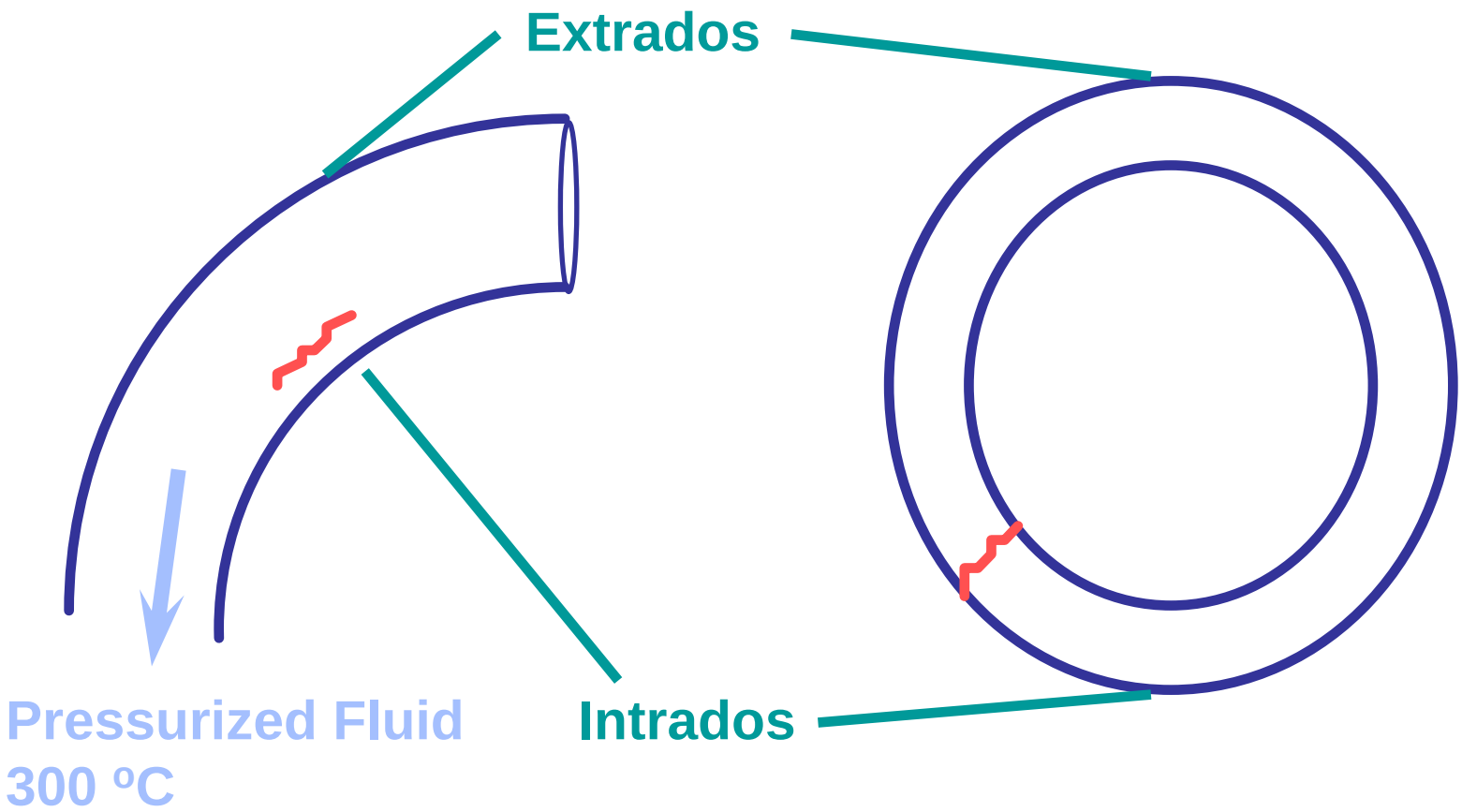
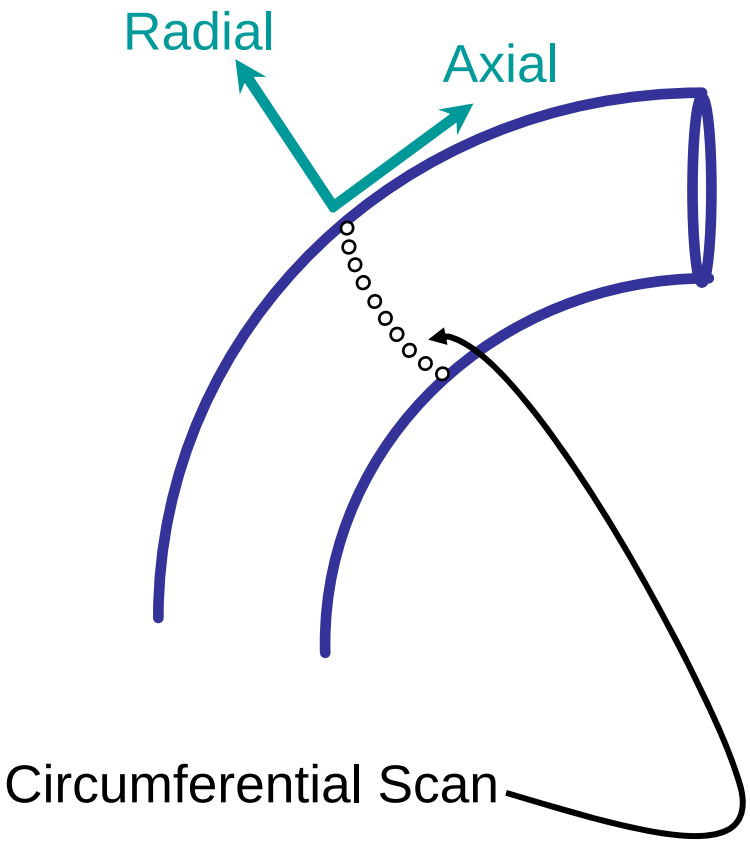
Failure analysis

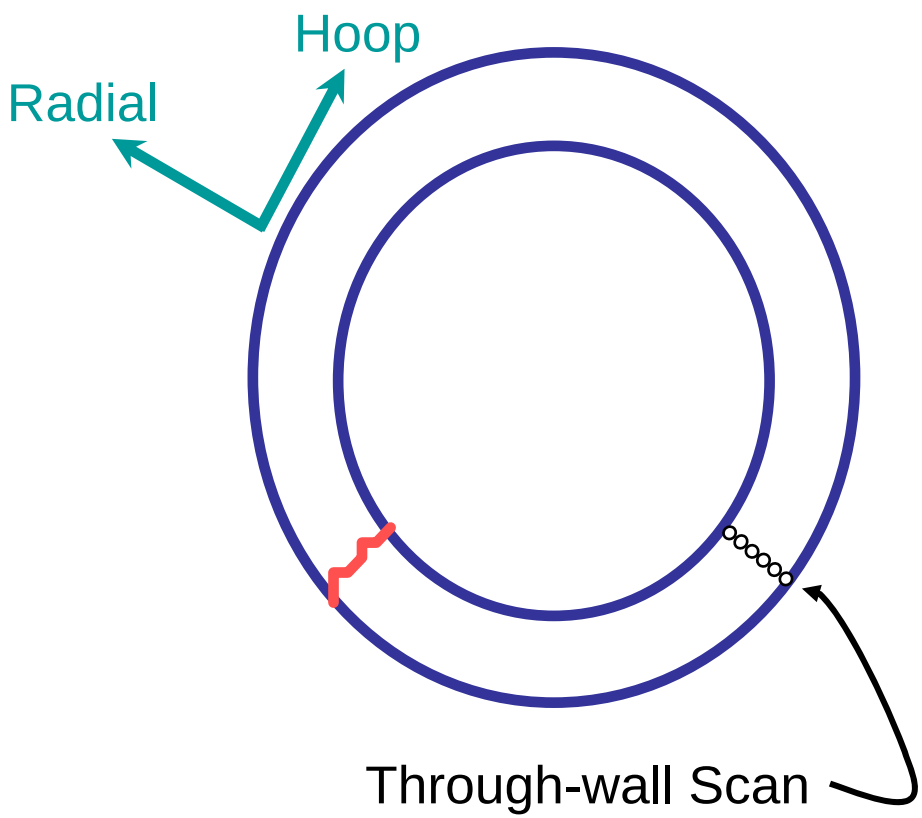
Through-wall crack in a bent pipe



Failure analysis

Scanning tracks, coordinates





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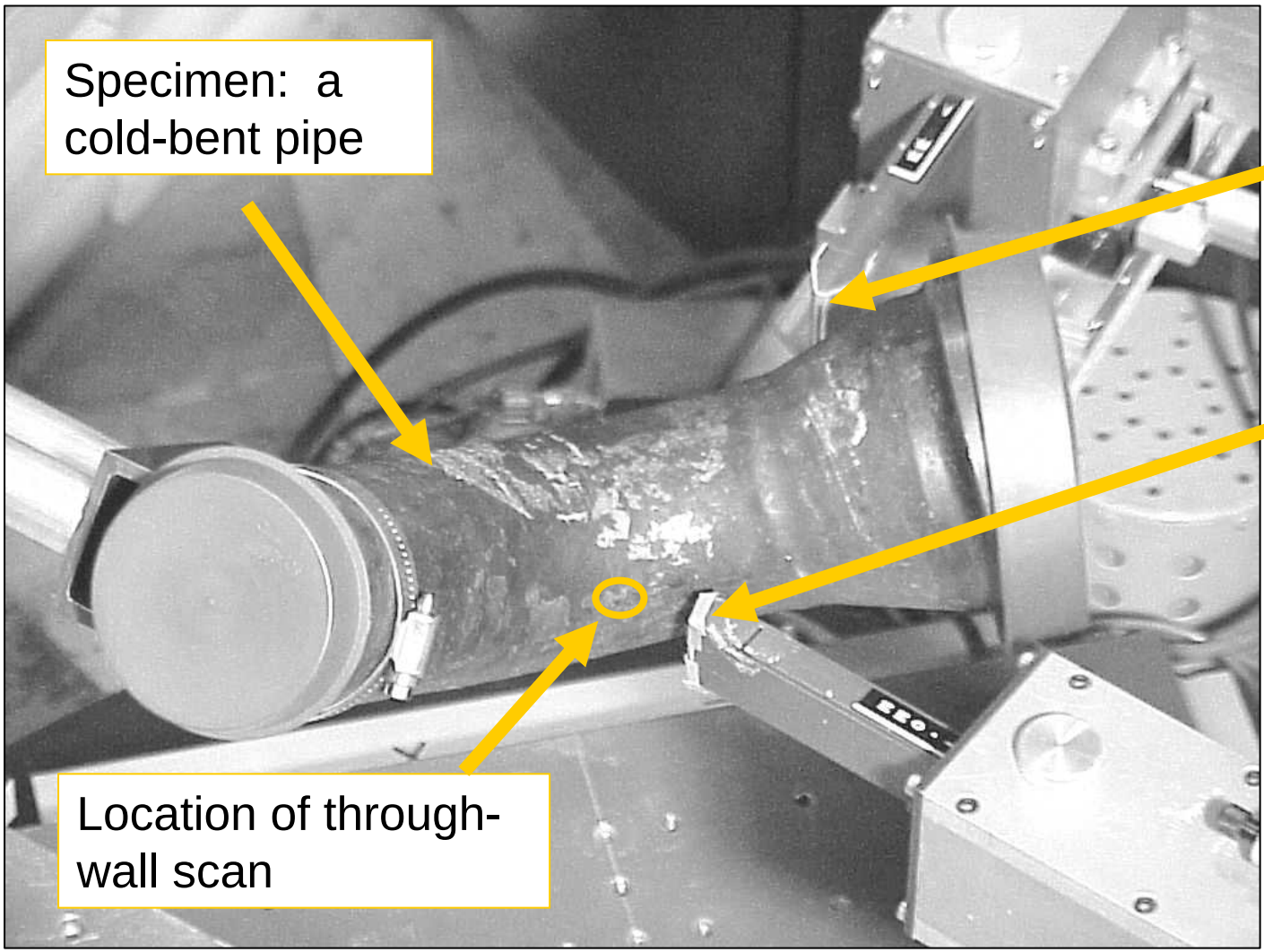
How it really looks

Strain parallel to tube axis

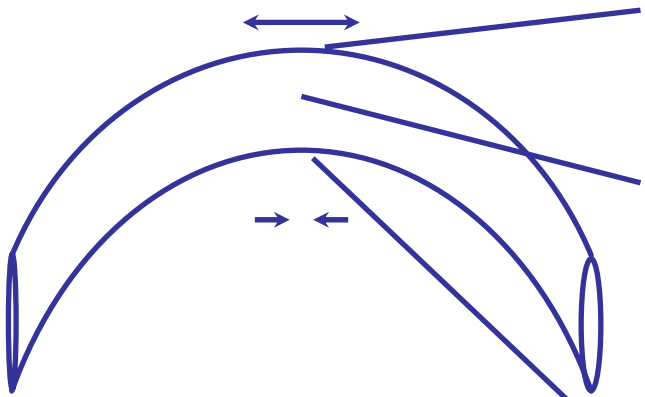


"Pixel" dimensions: 1 x 1 x 5 mm^3

Primary Stress

Axial stress from inhomogeneous yield

Apply a Bending Load

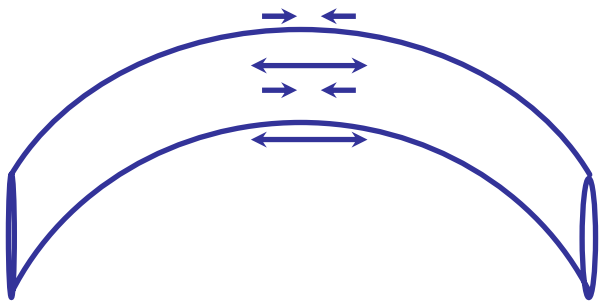


"Extrados" yields in tension

Elastic stress near neutral axis opposes bending load

"Intrados" yields in compression

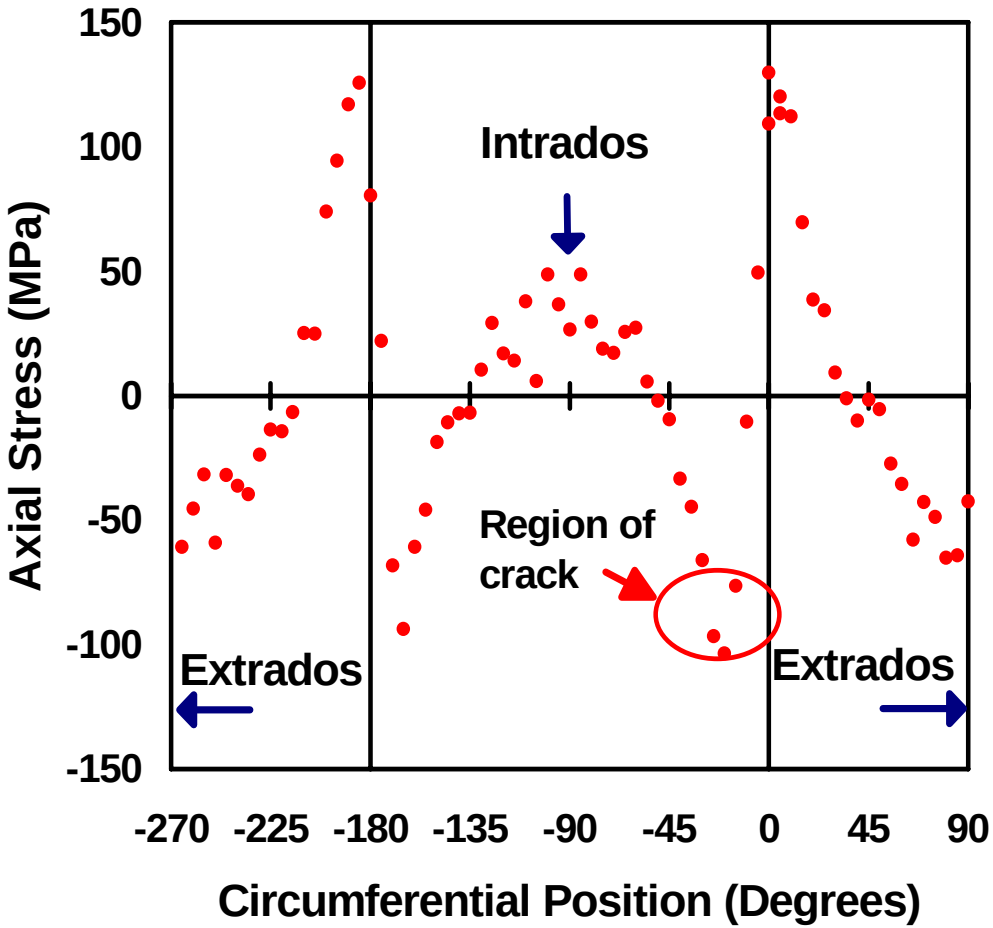
Release the Load



Residual stresses remain after partial "springback".

Primary Stress

Axial stress from inhomogeneous yield



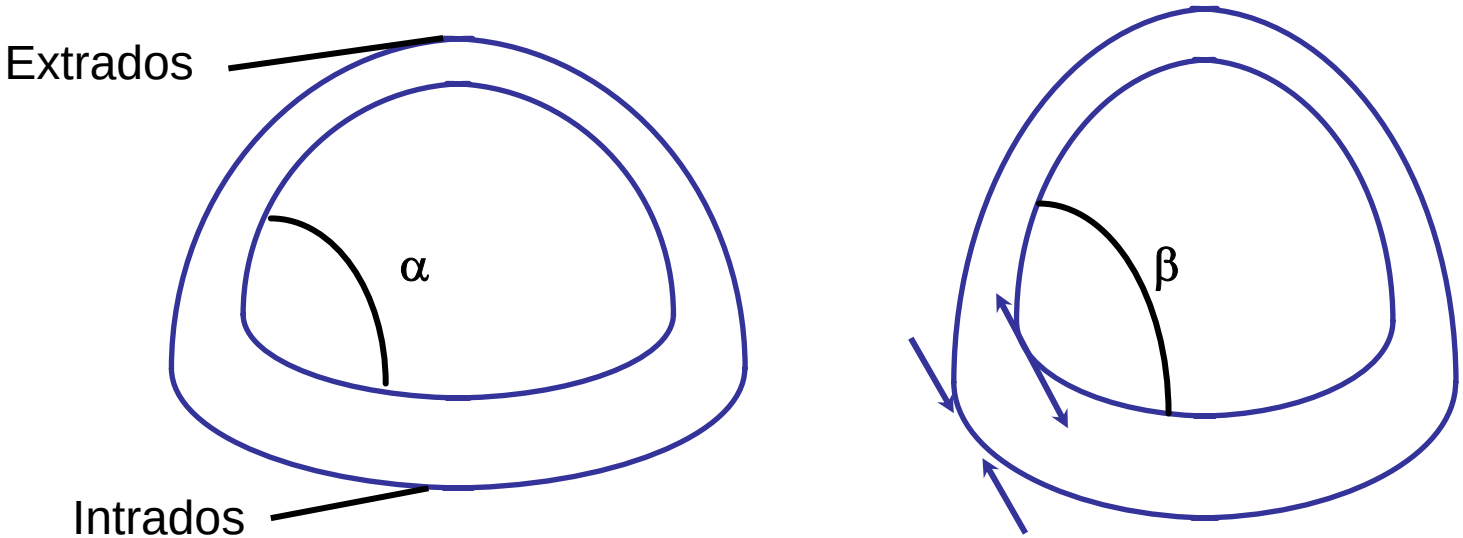
- Axial component of stress plotted vs. circumferential position.
- Averaging through-thickness of a thin tube (generic example).
- Sharp gradient of stress on passing the neutral axis of the bend, at the “flank” of tube.

Secondary Stress

Hoop stress from inhomogeneous yield

Under Load

Load Released "springback"



Included angle β is larger than α. There is HOOP tension on inner surface, compression on the outer surface.

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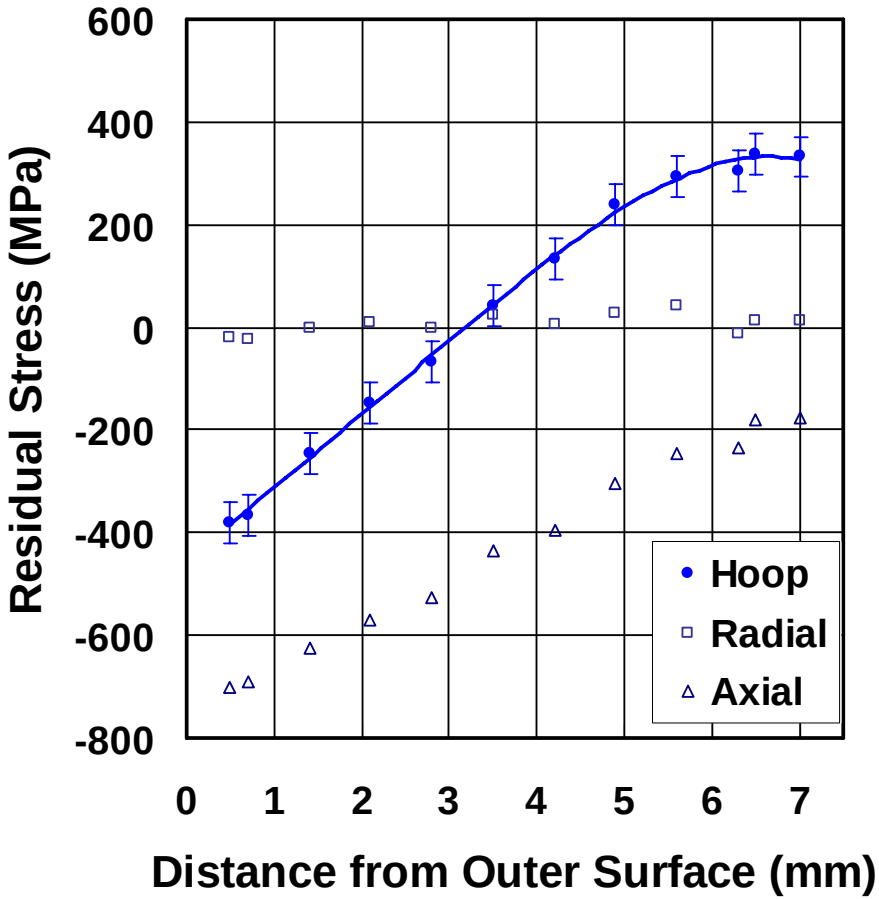
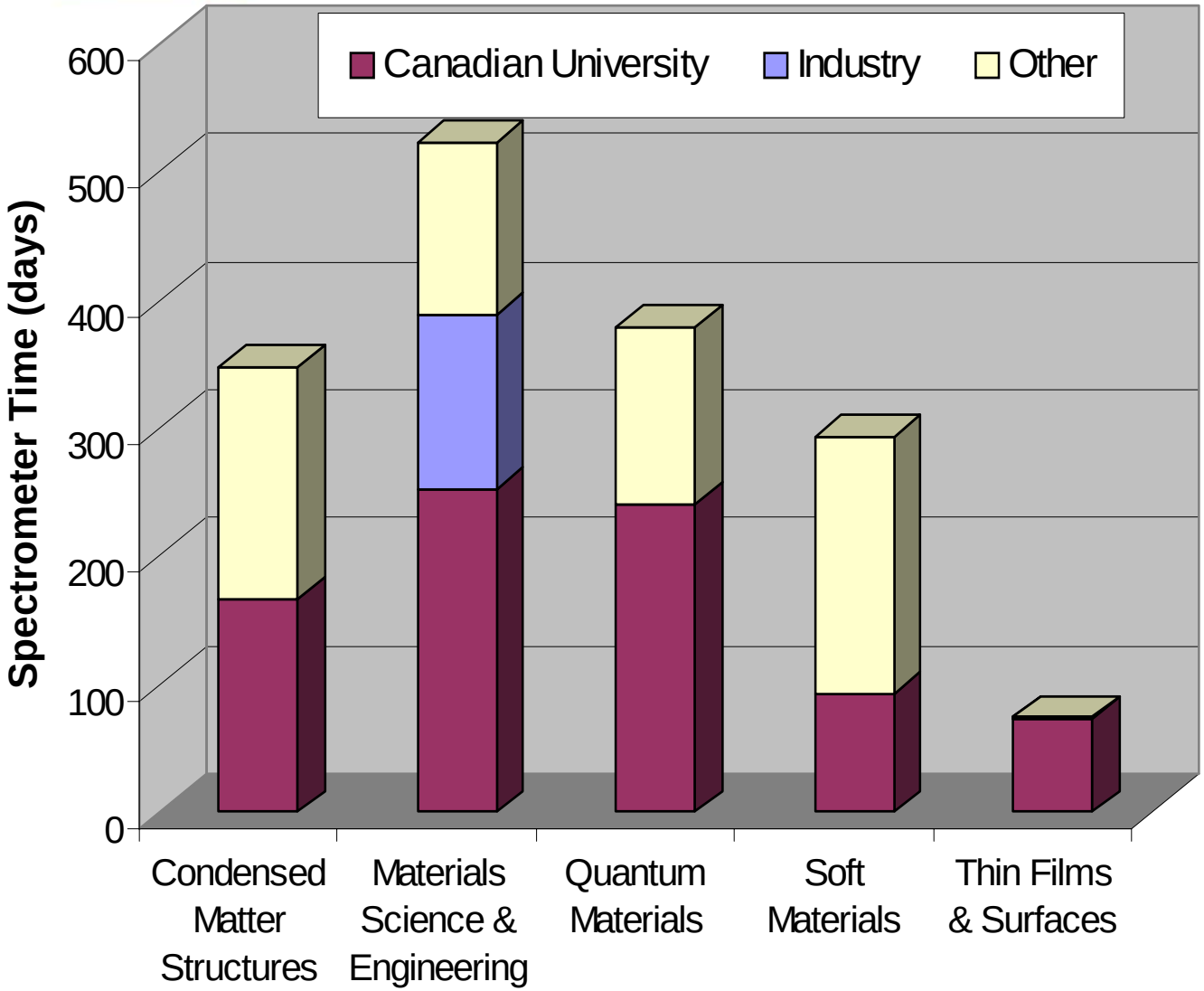
Stress distribution

From strains in 3 directions



- Tensile hoop stresses near the inside surface of our bent pipe are close to yield point of the material.
- These hoop stresses tend to accelerate growth of axial, through-wall cracks.

Industry access 2005/06



Access via fee-for-service contract

Rate ~ $340/h is full cost recovery

Results are private

Associated with "materials science" competency, at this time.

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Business summary

- Primary clients in nuclear, aerospace, automotive, oil&gas, materials producers, and manufacturing sectors.
- Main applications relate to safety, regulations, prototype evaluation and computer model validation
- Business predominantly based on non-destructive scanning of residual stress

  ~ 200 projects over 20 years of ANDI operation
  ~ $500K / year revenue on average, $678K in 2005/06

- Facility rate based on full cost of operation of the NRC's Canadian Neutron Beam Centre divided by available neutron spectrometer hours.
- Personnel charged at standard government rates (with overheads).
- Materials and services, including cost of neutrons provided by the NRU reactor, re-billed at cost.

http://neutron.nrc-cnrc.gc.ca/andi/andi.html

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Philosophical matters
(Xun-Li's questions)

- Industry pays full cost of access (~ $57K/week), but government maintains infrastructure in a state of readiness for access.

- Industry access is compelling evidence that neutron facilities are valuable assets for the entire, national 'innovation system': universities, industries and government laboratories.

- Considering price, turnaround, advertising, unique capabilities, etc. the #1 key to our success is *RELIABILITY*. It is essential that all neutron facilities maintain a standard of excellence in quality of data, respect of deadlines, open communication with clients, etc. It must be taken as a given that "Neutrons never lie!" *

* T.M. Holden, ~ late 1980's at Chalk River, Canada