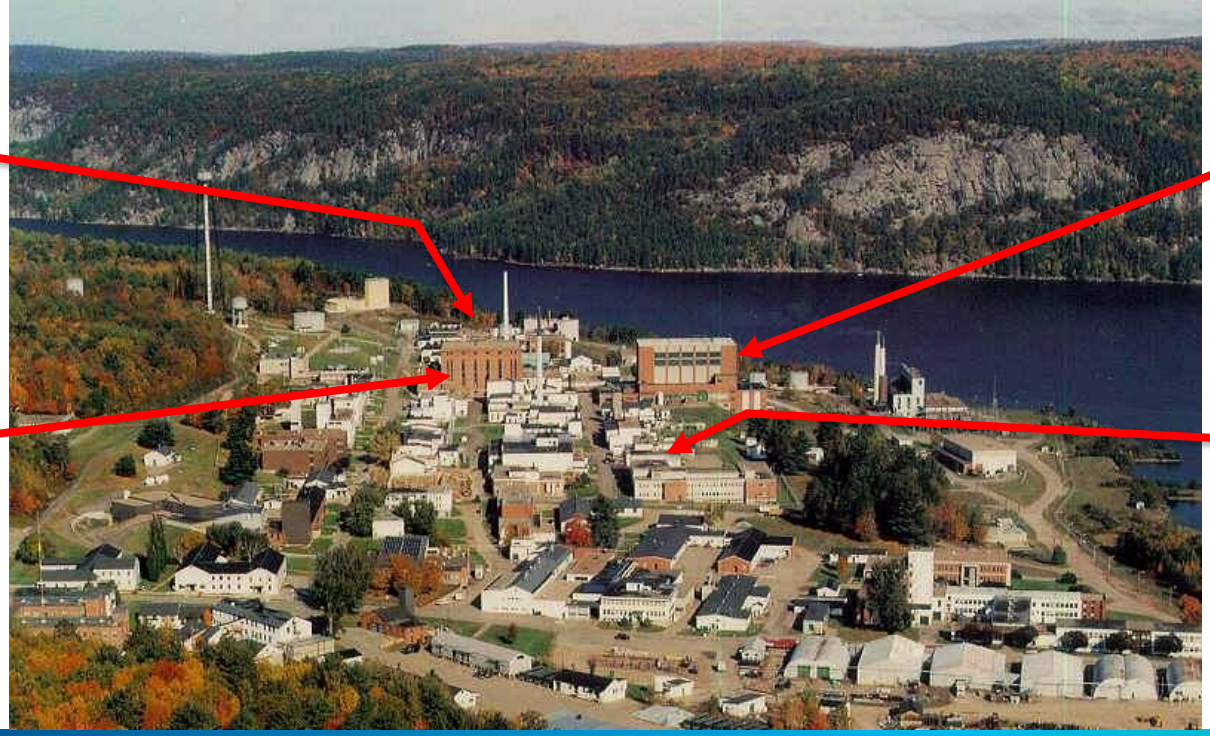


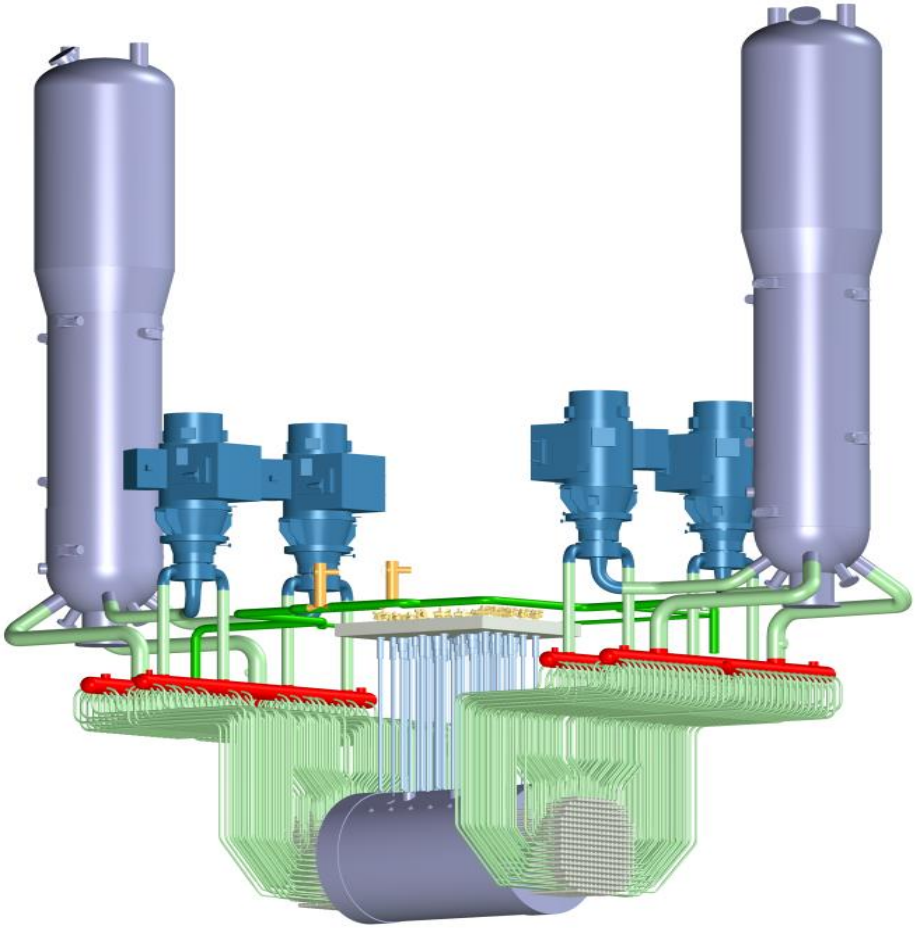
Neutron Beams for Lifetime Prediction, Failure Analysis, Informed Inspection, Qualification…

Ron B. Rogge

Canadian Neutron Initiative roundtable towards a National Neutron Strategy, 2020 December 15,16

Nuclear Industry

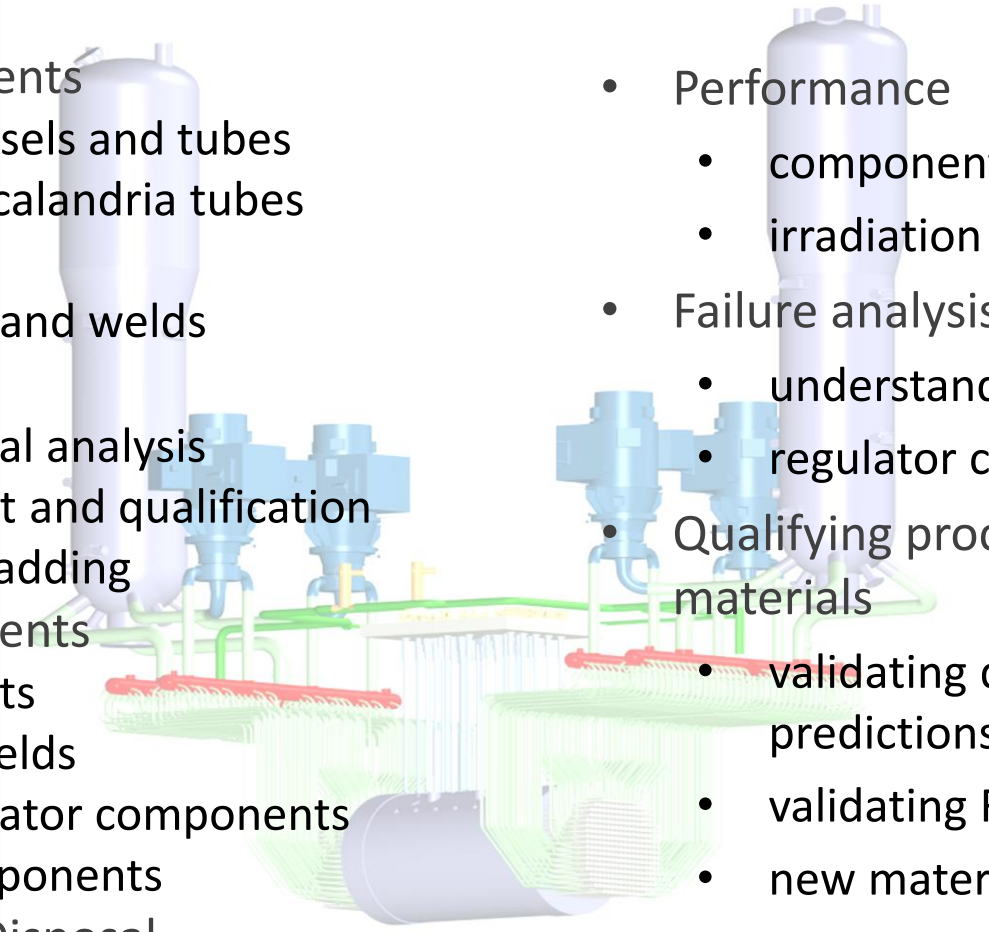
Scope of Materials Challenges



Nuclear Industry

Scope of Materials Challenges

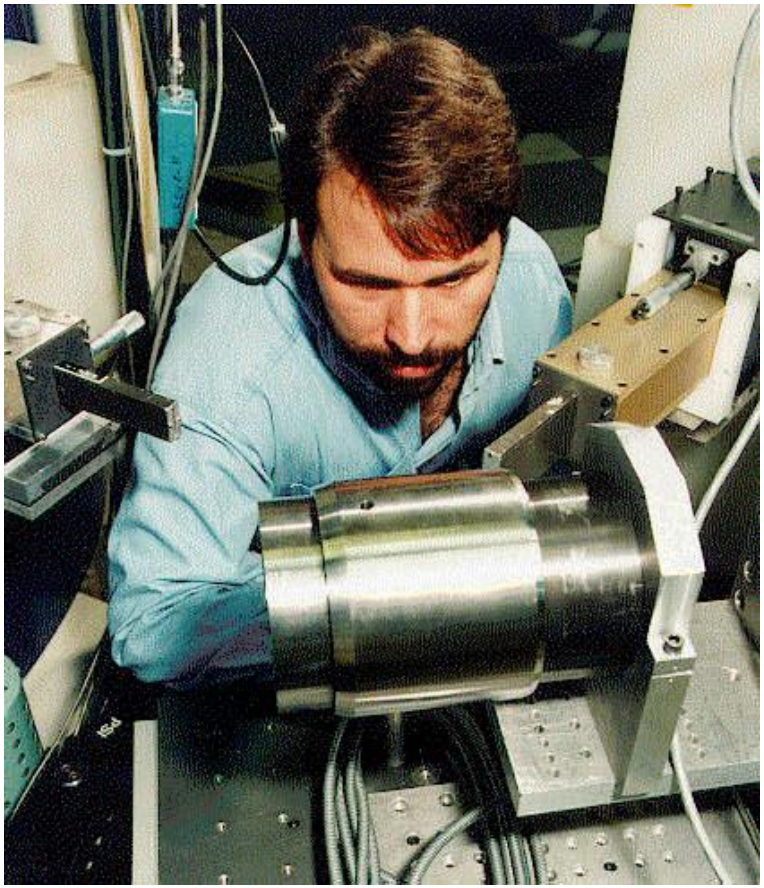
- In-core components
  - pressure vessels and tubes
  - calandria & calandria tubes
  - spacers
  - rolled joints and welds
- Fuels
  - compositional analysis
  - development and qualification
  - poisons & cladding
- Ex-core components
  - feeder circuits
  - joints and welds
  - steam generator components
  - turbine components
- Nuclear Waste Disposal



- Performance
  - component lifetime
  - irradiation effects
- Failure analysis
  - understanding failure
  - regulator concerns
- Qualifying processing changes or materials
  - validating designed performance predictions
  - validating FEM
  - new material/supplier
  - radical new design
  - maintain quality standards

Predicting Performance

Life-Time Stress Relaxation Stresses in a Rolled Joint



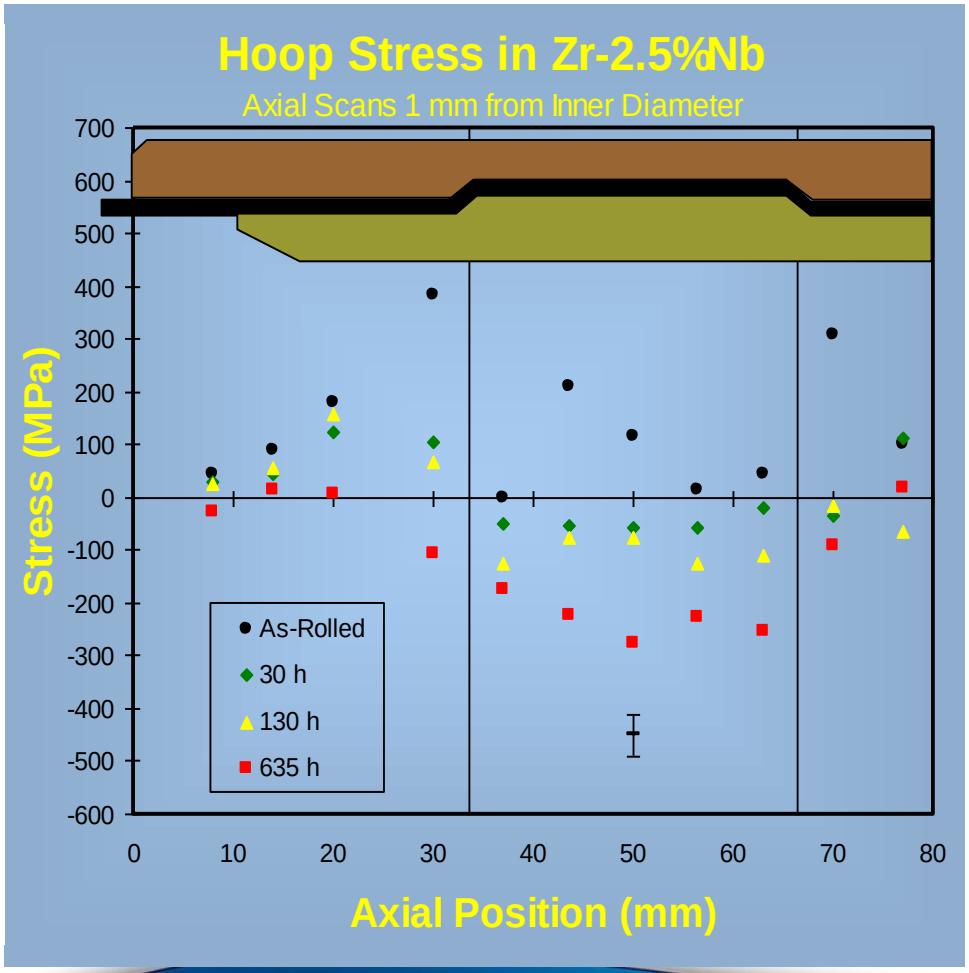
Will the residual stresses relax over the projected 30-yr lifetime of the reactor?

- Map residual stresses in as-rolled joints.
- Heat-treat at elevated temperature (350 C vs. 288 C) to accelerate stress relaxation (30 h ⇨ 1 yr, 635 h ⇨ 30 yr).
- Re-evaluate residual stresses at identical locations after each heat treatment.

M. Hayashi *et al.* Proceedings of the 14th Int'l Conf. of Non-Destructive Evaluation, Nuclear and Pressure Vessel Industries, Stockholm, Sweden (1997).

Hoop Stress After Heat Treatments

Action is in the Zr-2.5Nb

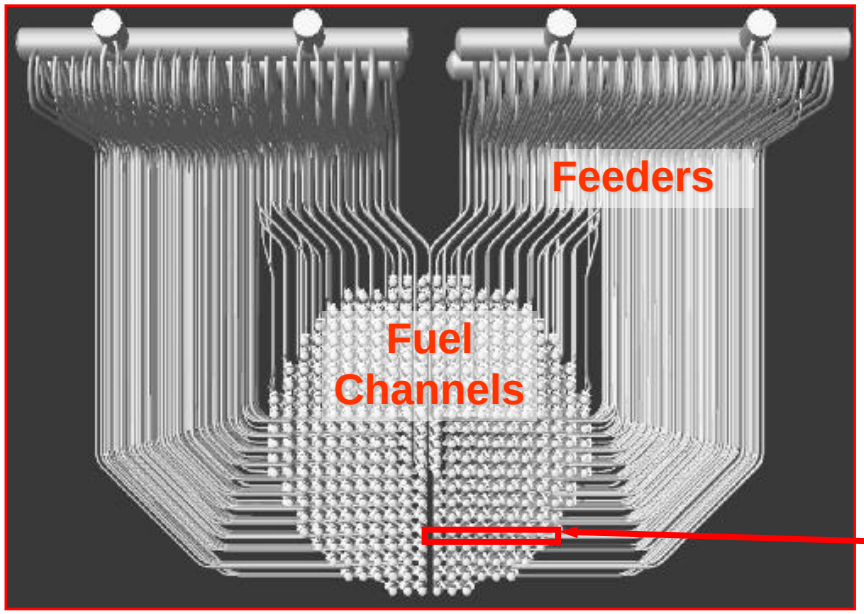


- Continuous change as heat treatments proceed
- Outside of crimp stresses tend to relax
- Over crimp region stresses shifted from tensile to compressive
- Is cycling an issue?

Over the proposed 30-year lifetime, stresses will relax in the sleeve and extension and become compressive (favourable) in the Zr-2.5Nb

Failure Analysis

An *Ordinary* Bent Steel Pipe in the Heat Transport System

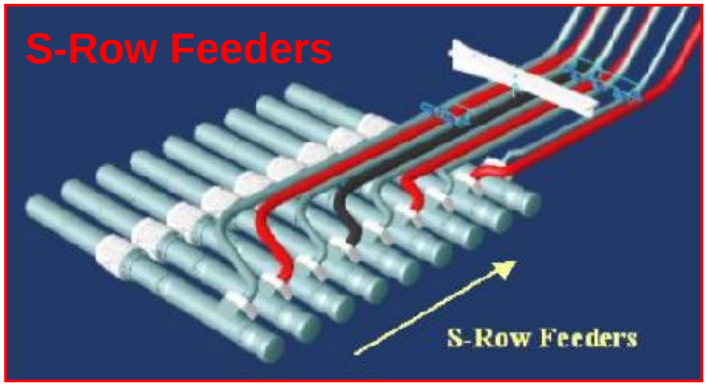


A CANDU plant has 380 to 480 fuel channels

⇒ 760 to 960 feeder pipes

Scale of the problem is potentially huge

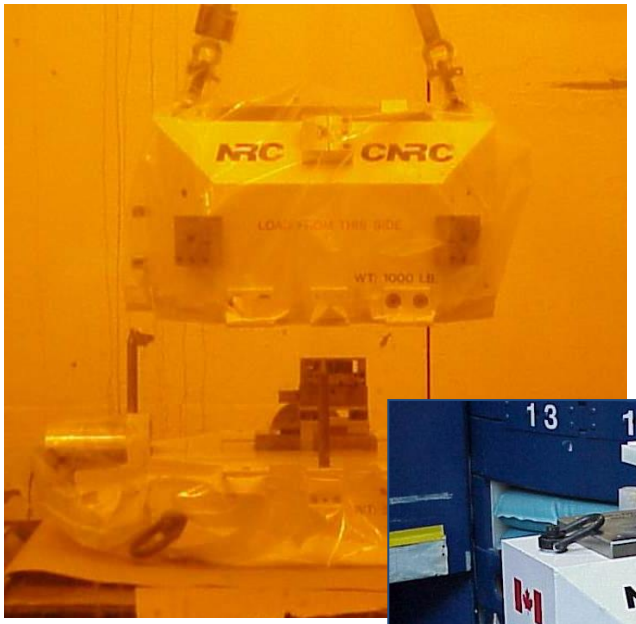
⇒ rapid response essential



Images courtesy of AECL

Stress Changes Due to Fast Neutron Irradiation

Need Three Sample Orientations to Determine Stress

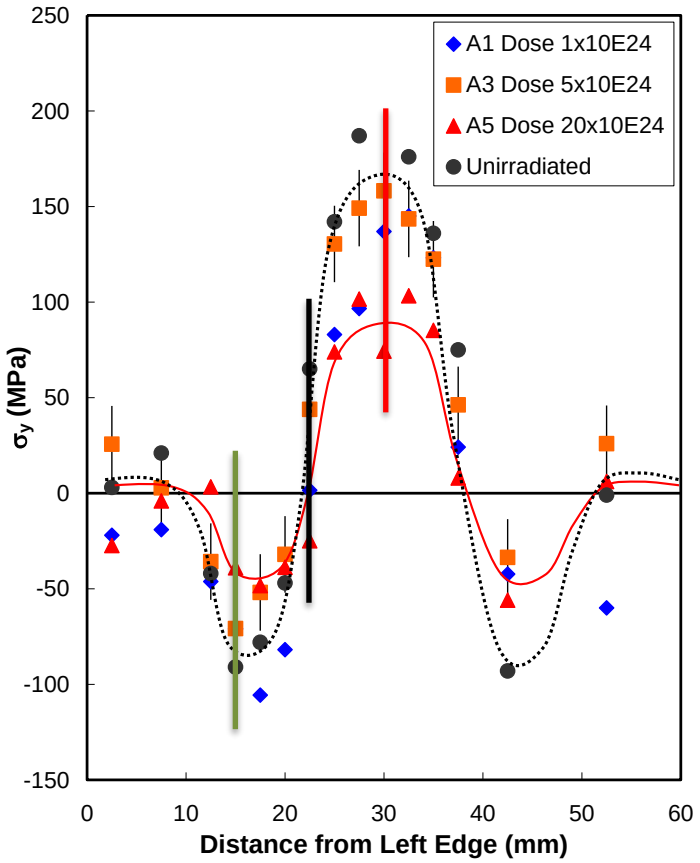


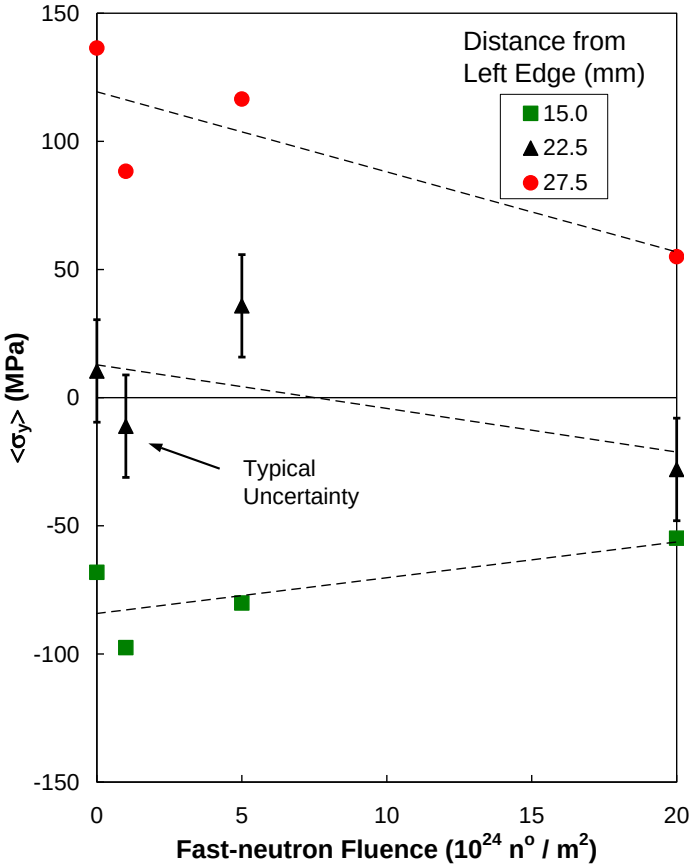
- Sample, main source is ^{60}Co
- 200 Sv/h (20 000 R/h) on contact
- Analysis gave 1.4 TBq on most active sample

- Min. 12.7 cm (5”) Pb path
- Weight, 682 kg (1,500 lbs)
- Shield, 20-40 μSv/h (2-4 mR/h) near contact
- Through ports, 2-10 mSv/h (0.2-1 R/h) at exit
- No impact on ^{3}He detector

Stress Data vs. nº Fluence

304 Stainless Steel





M.Obata *et al.,* Proc. 22nd Symp. on Effects of Radiation on Materials, ASTM, Boston (2004)

Powder Diffraction of Active Samples

Phase Analysis of Irradiated Fuel

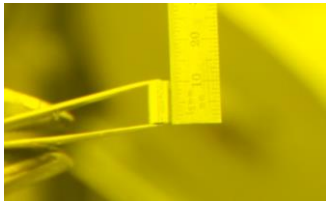
Near contact, gross γ-fields

Sample:

750 mSv/hr (75 Rem/hour).

Shielded Cell:

0.3 μSv/hr (30 mRem/hour)

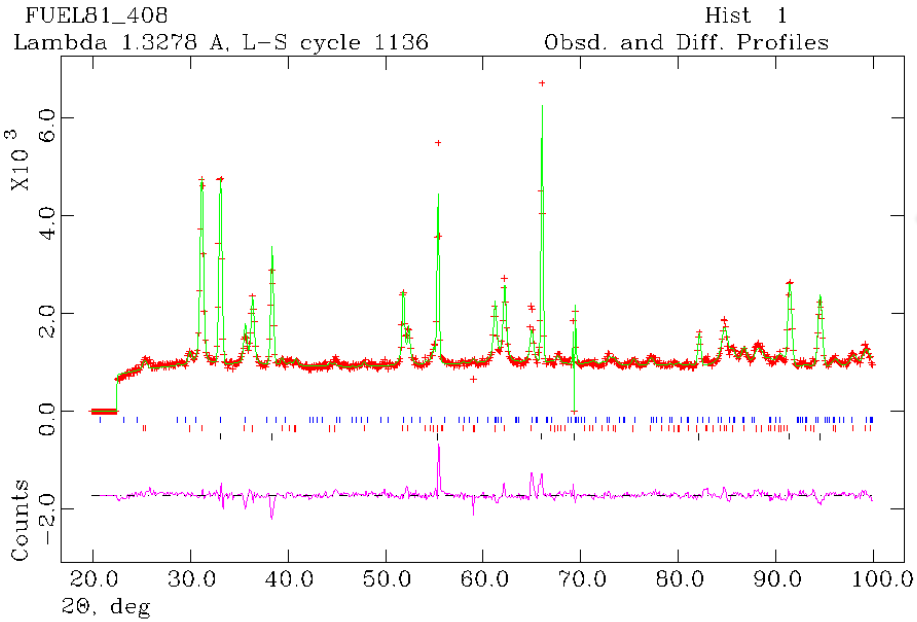


- 300 kg shielded cell
- 80 deg. exit window
- sample is *captive*

AECL EACL

INL Idaho National Laboratory

NDA Results From Al-U_3Si Fuel

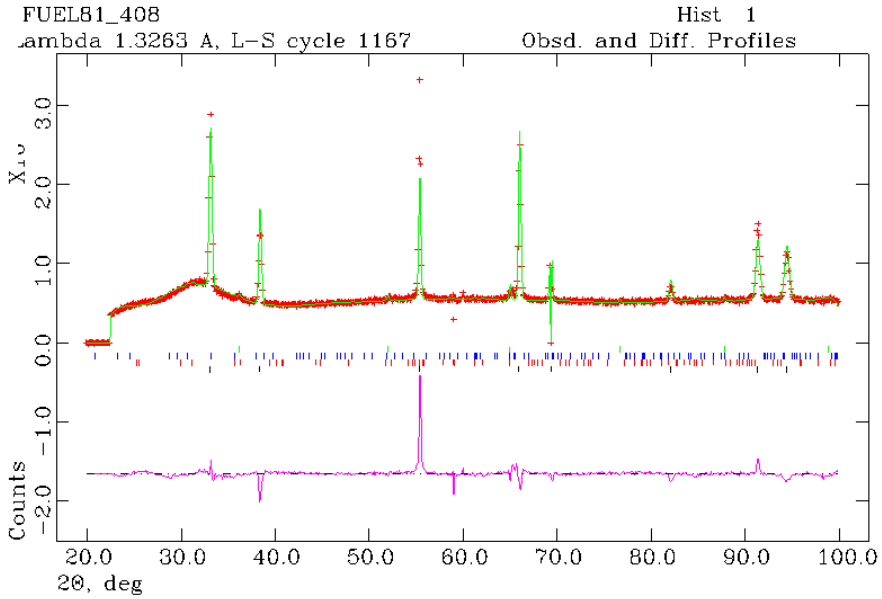


Unirradiated

See peaks that correspond to Al matrix, and U_3Si fuel

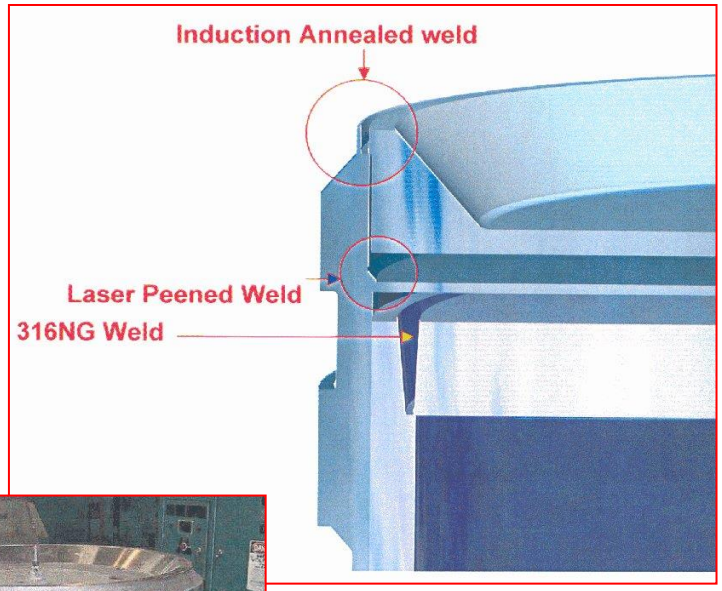
Irradiated to 90 at% Burnup

Peaks *only* from Al matrix



Ensuring 10,000-Year Longevity

Weld Stress Mitigation



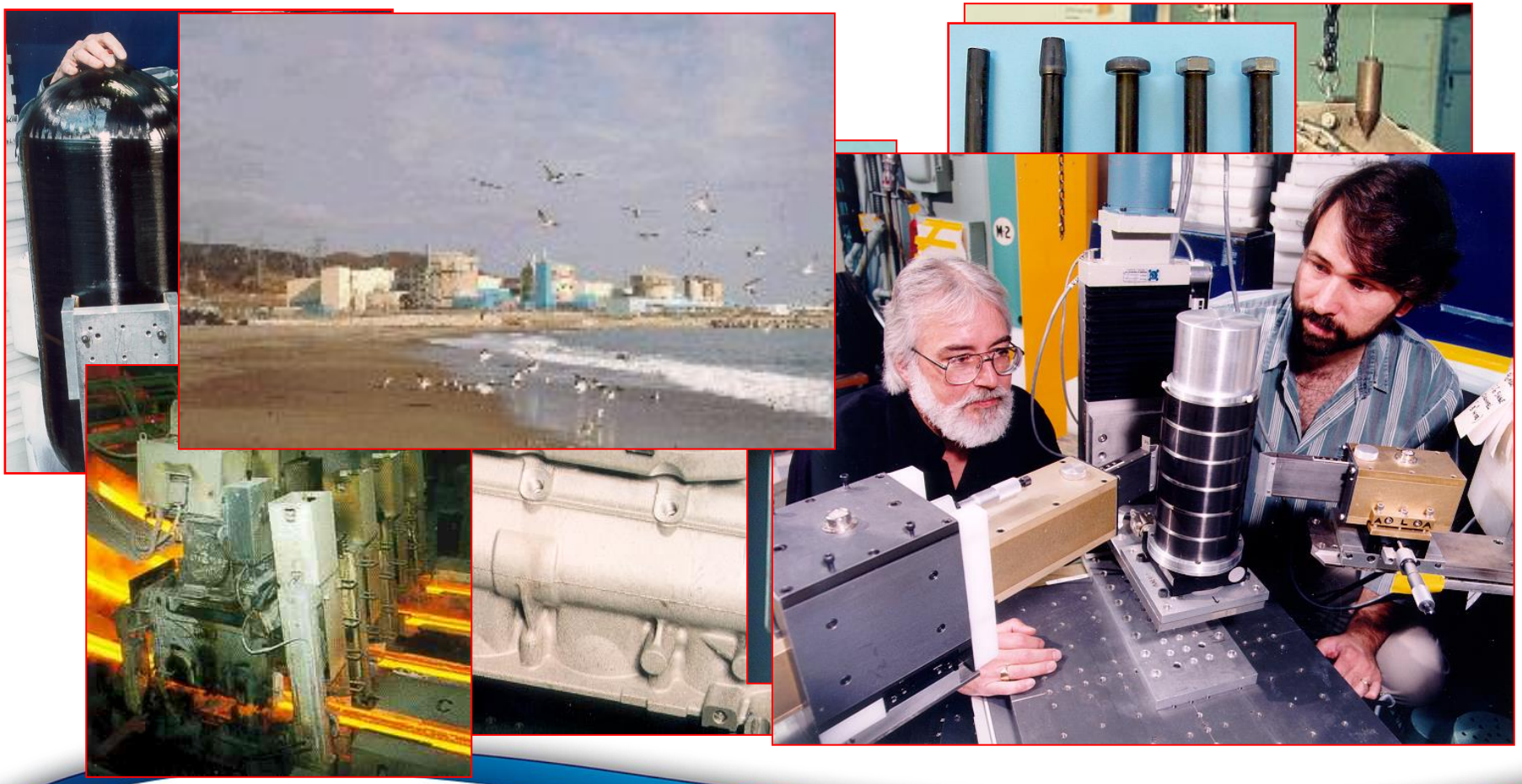
- Stress can assist corrosion
- Client has *challenging* corrosion avoidance requirements
- Welding generally produces unfavourable tensile stress
- Stress mitigation:
  - Heat treatment
  - Stress modification

Laser peening or low plasticity burnishing are only practical (robotic) options, but…

Are they effective?

ANDI

Innovation, Regulations and Productivity



ANDI

Managing Risk and Performance

Industrial Access

What It Looks Like

- Client rarely has in-house neutron experts
- Occasional, but immediate access:
  - mitigate financial loss due to immediate problem
  - short-term S&T horizon
- Service preferred over collaborative research agreement
- Proprietary information or exclusive to industrial sector
- Sample itself might be protected (security)

Industrial Access

What It Looks Like

- Rapid turn-around requires nimble contracting and legal system
- Projects often <$50,000
  - cost-effective to have simple agreement template
  - jurisdictional challenges of international agreements
- Clients can be industrial, government, or military
  - National security/sovereignty implications
- Flexible multi-organization partnerships with mix of public domain and proprietary data
- Knowledgeable liaisons between industry & facility