Residual stress measurement: why, when, where and how?

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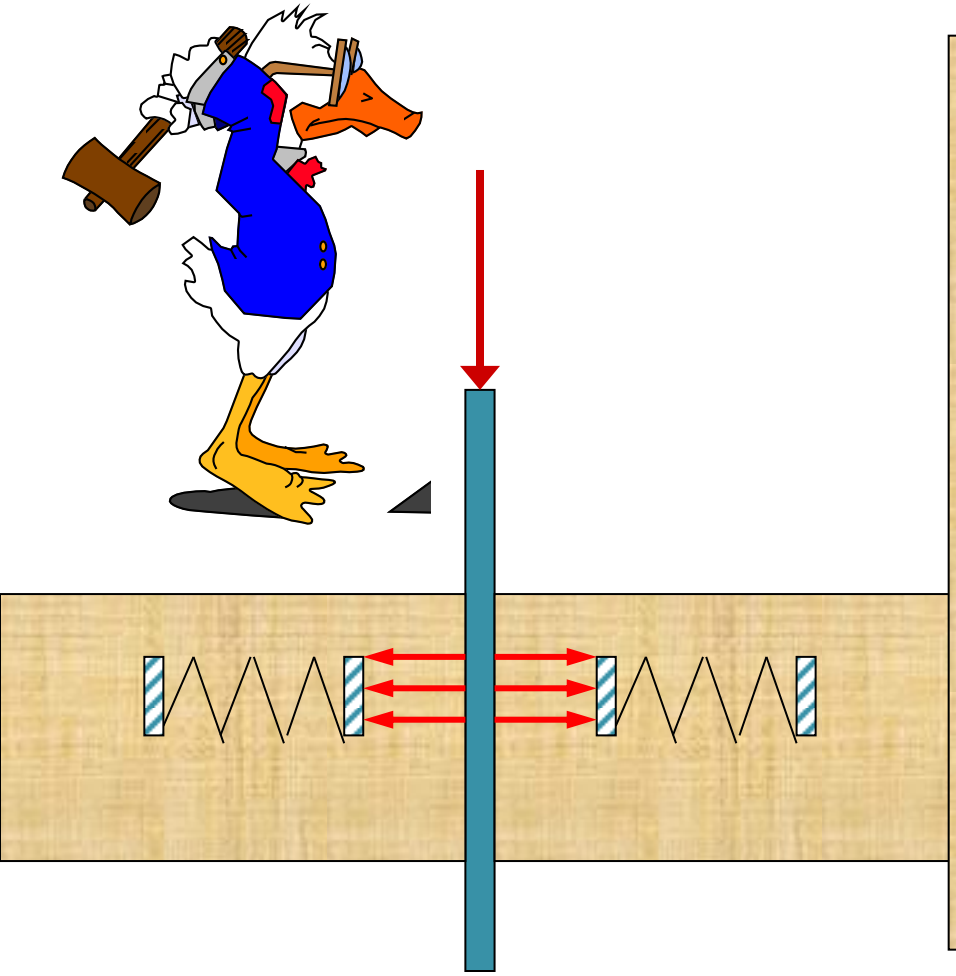
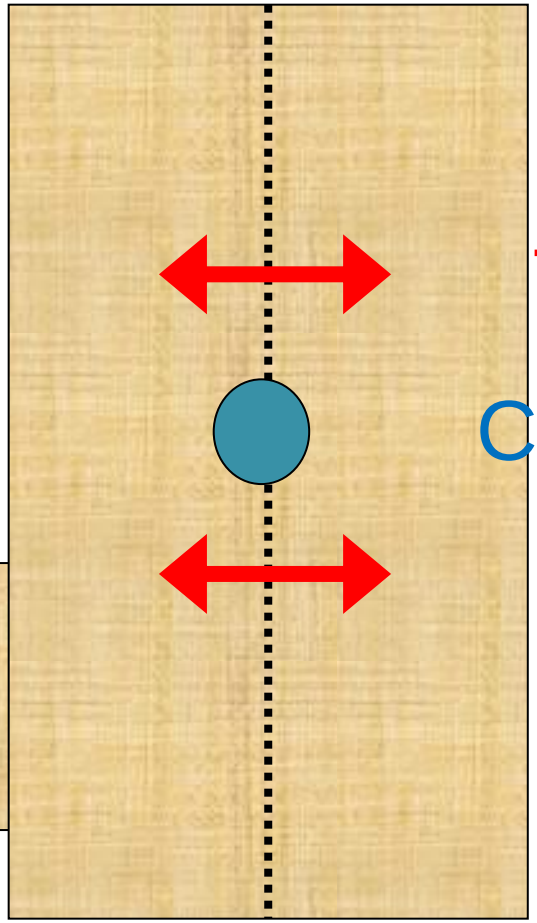
Residual stress measurement: why, when, where and how?





Tension

Compression

Tension

Built-in Stresses?

Residual Stresses are:

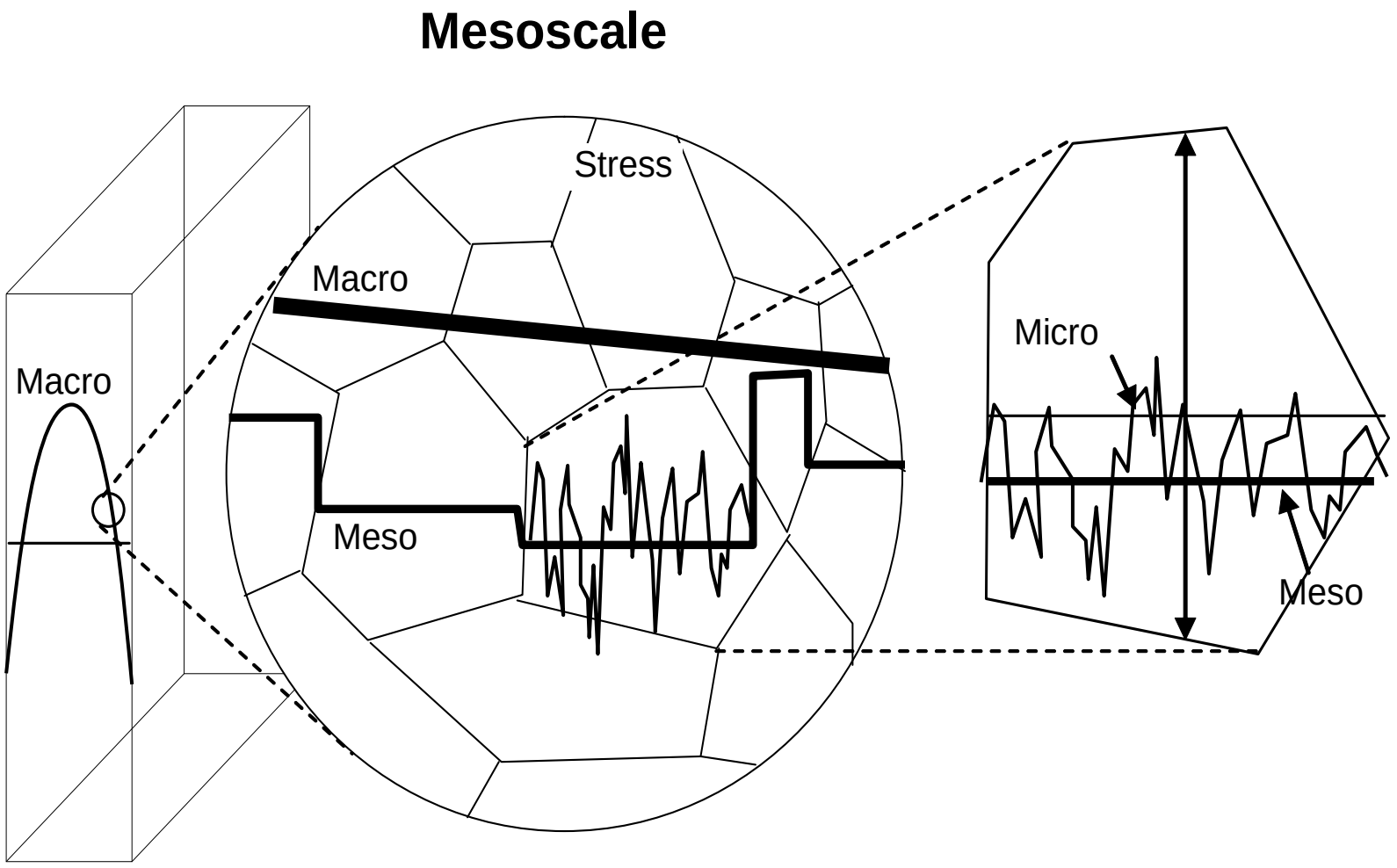
Built-in Stresses

Locked-in Stresses

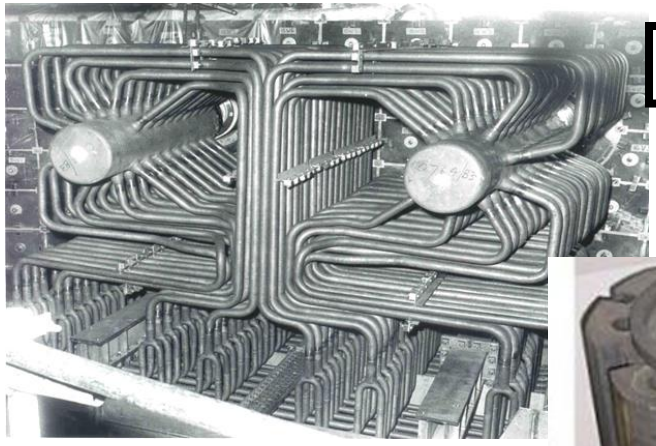
Inherent Stresses

Growth Stresses

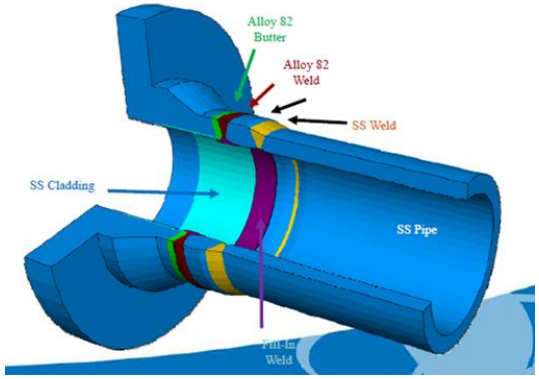
Residual stresses at different length scales



Residual Stresses and Structural Integrity



Boiler tubes



PWR Nozzle

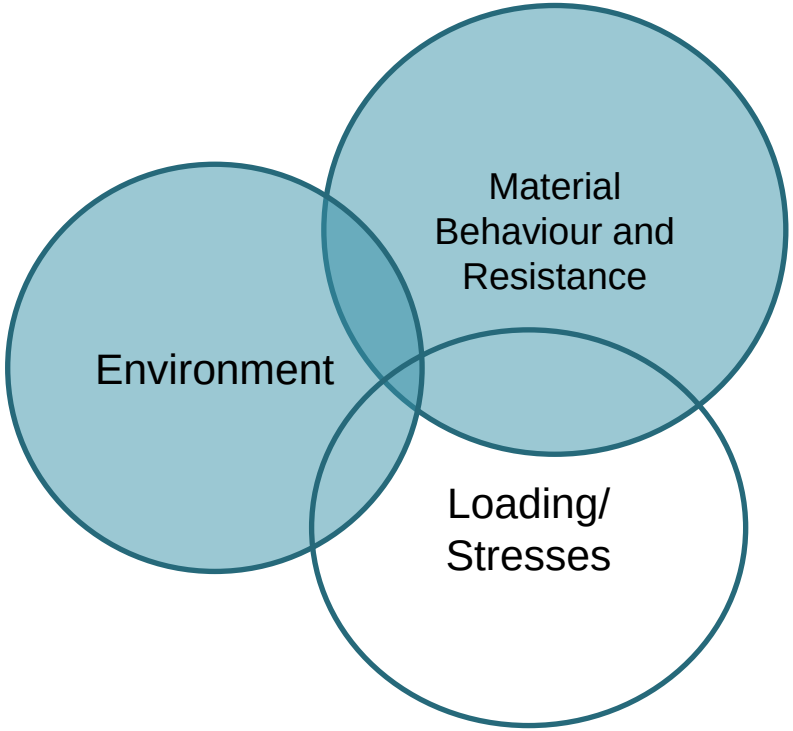
AGR Graphite Brick

All these safety critical components may crack especially as the material degrades

A driving force for failure is the residual stress: start of life and during life

Modes of failure: Brittle and ductile fracture, fatigue cracking, stress corrosion cracking, creep, ductile rupture, oxidation,.....

Residual stress measurement: **why**, when, where and how?

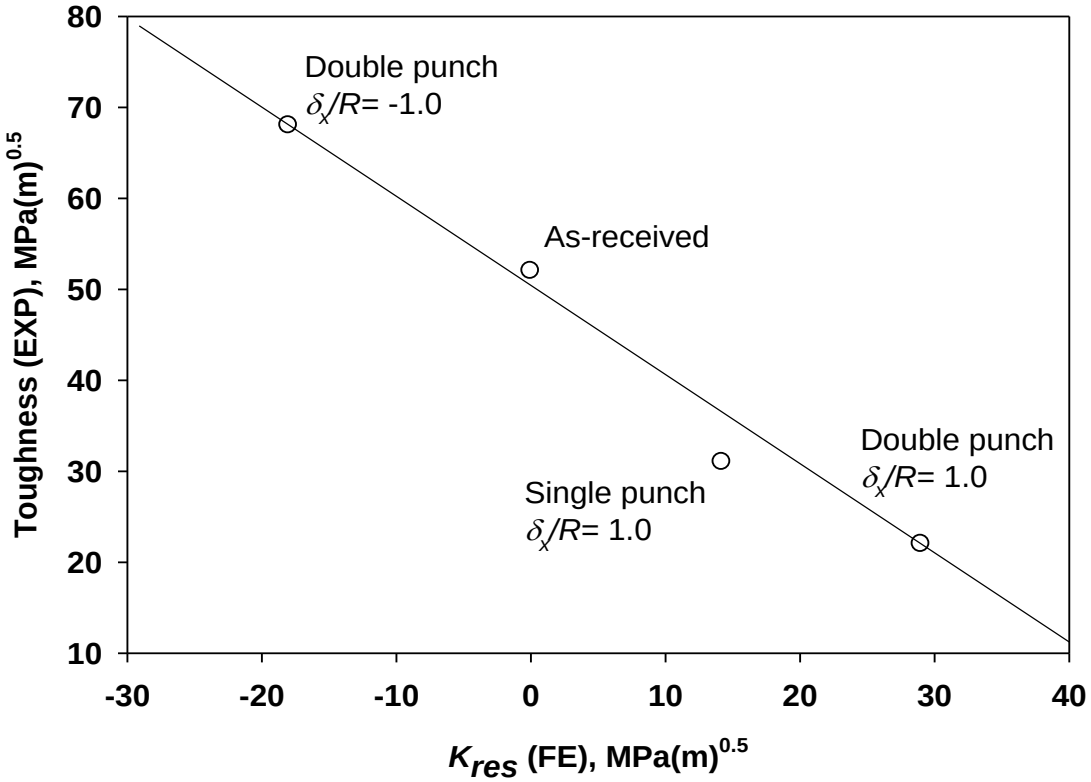


Component Safety, Performance and Life

- **<u>What are all the loads and stresses</u>**?

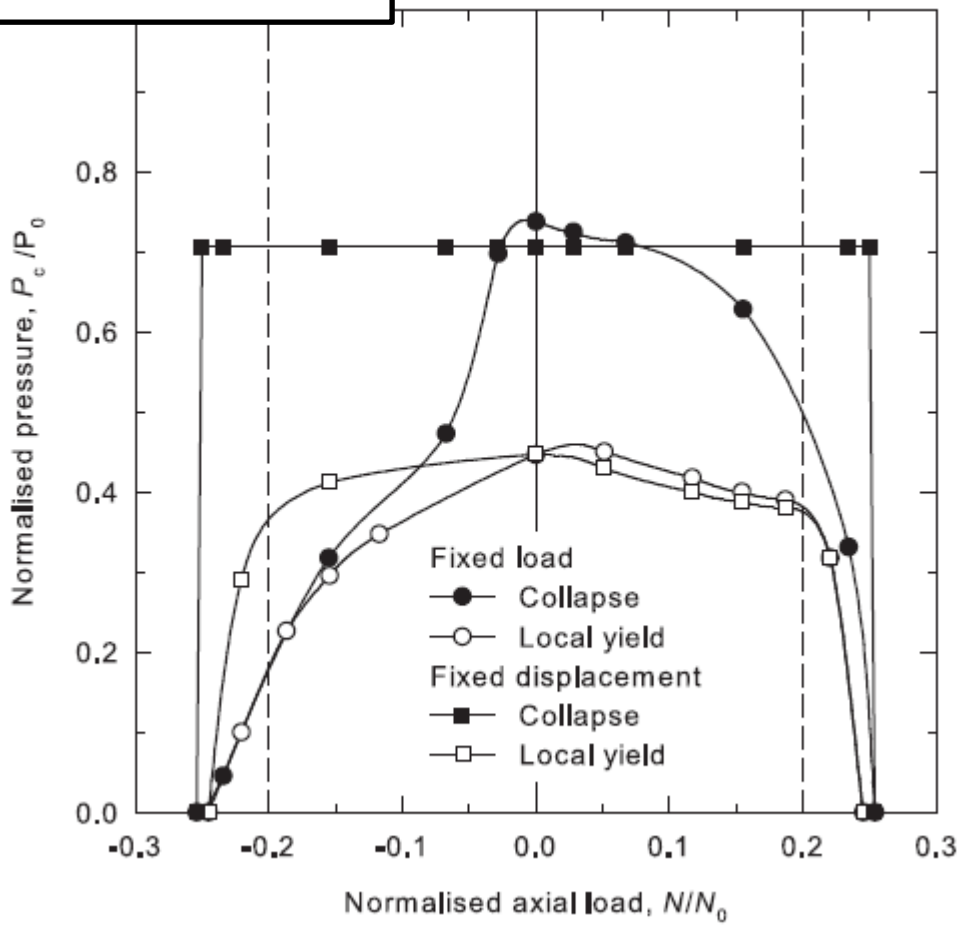
What is the mode of failure? : brittle and ductile fracture, fatigue cracking, stress corrosion cracking, creep, ductile rupture, oxidation,.....

Low Ductility Fracture: linear superposition of applied and residual K



$$K_{res} + K_{app} = K_T \geq K_{mat}$$

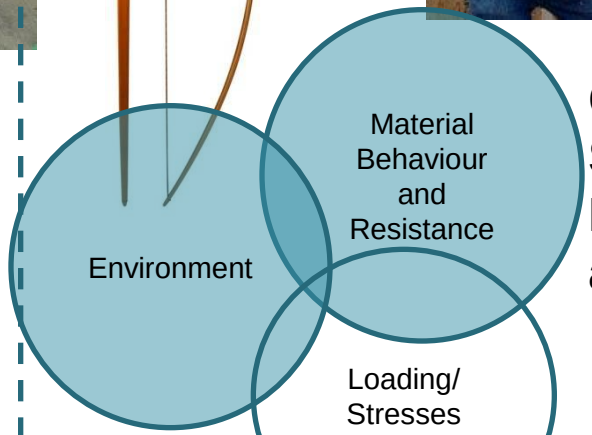
Plastic collapse of pressurised pipes containing long range residual stress: no effect of residual stress



Structural Integrity applied to LONGBOWS

Initial locked-in stress + Applied stress

= Total stress



Component Safety, Performance and Life

OK if less than fracture stress!

Broken bow!

Residual stress measurement:

<u>why</u>, when, where and how?

Residual + Applied = Total < Failure stress

Initial locked-in stress

This is adequate in this simple example:

Recall residual stress is a consequence of misfit

If the misfit is reduced or completely relieved then:

Applied = Total < Failure stress

Therefore:

0 ≤ Residual stress < Failure stress

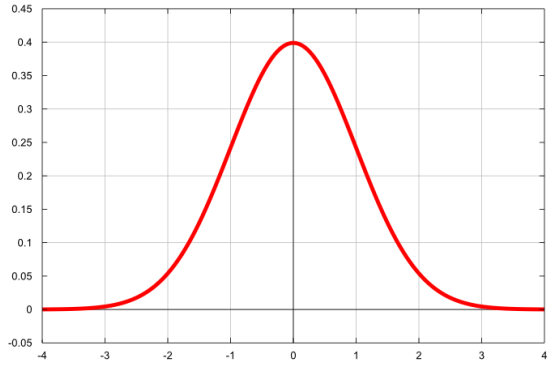
Residual stress measurement:

why, **when,** where and how?

Initial locked-in stress

If all longbows were **ALL** made the same way using the **SAME MATERIALS** : we would only need to measure the locked-in stress **ONCE**! Although samples would be taken to confirm consistency.

Manufacturing methods would give a distribution of values



Residual stress measurement:

why, **when,** where and how?

An Imagined Catalogue of long bow locked-in stresses

Initial locked-in stress

Long Bow Type	Mean Stress, MPa	Standard deviation, MPa
Ash	60	10
Oak	80	8
Willow	40	2
Etc....	.....	....

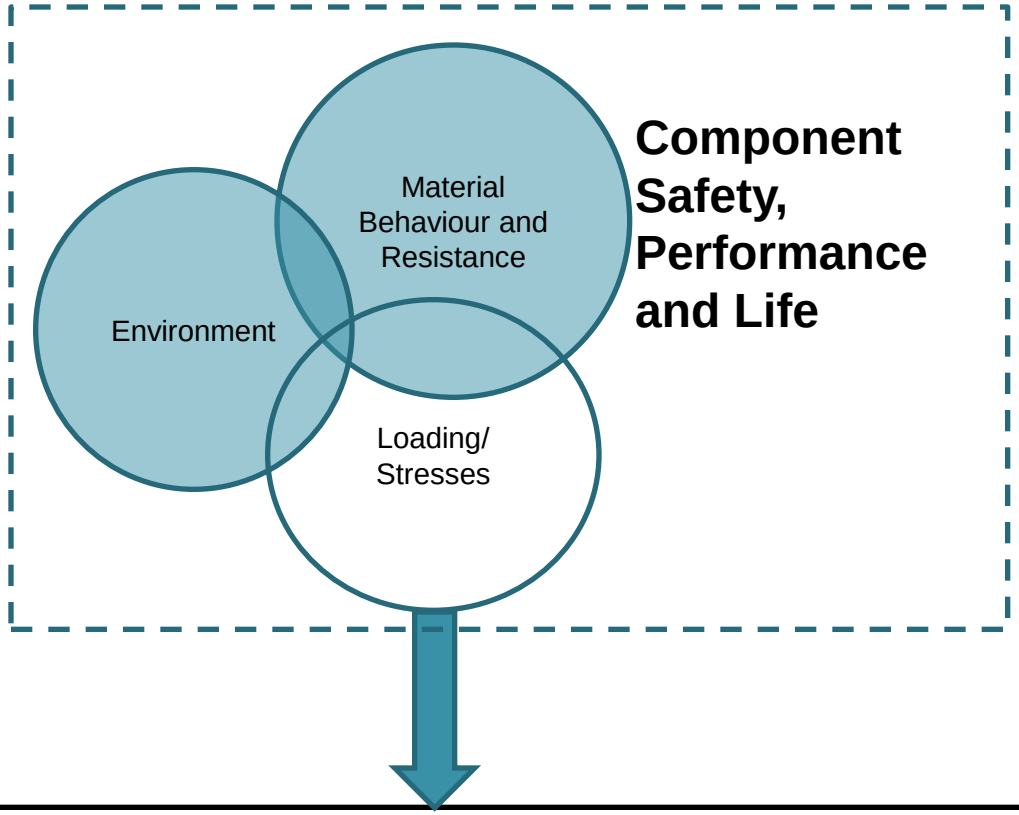
Step 1: Look up the catalogue-
if not in catalogue then **MEASURE**

Step 2: Insert value into analysis

Residual + Applied = Total < Failure stress

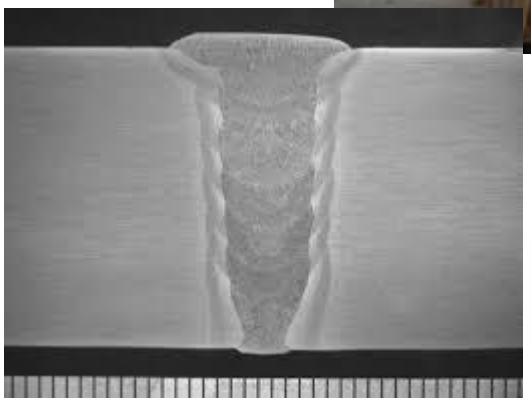
Step 3: Decide if acceptable

Residual Stresses and Structural Integrity



Manufacture of **WELDS** leads to locked-in stresses/forces

These <u>stresses combine</u> with the applied stresses e.g. internal pressure to create the total stress

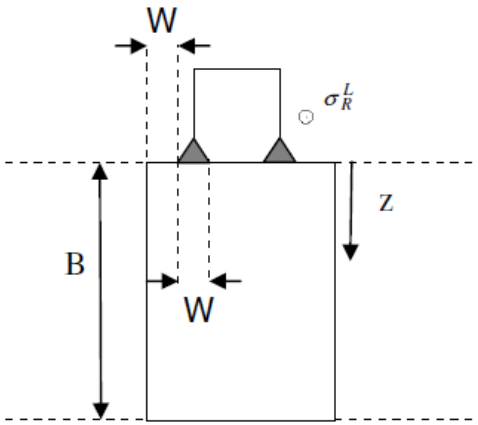


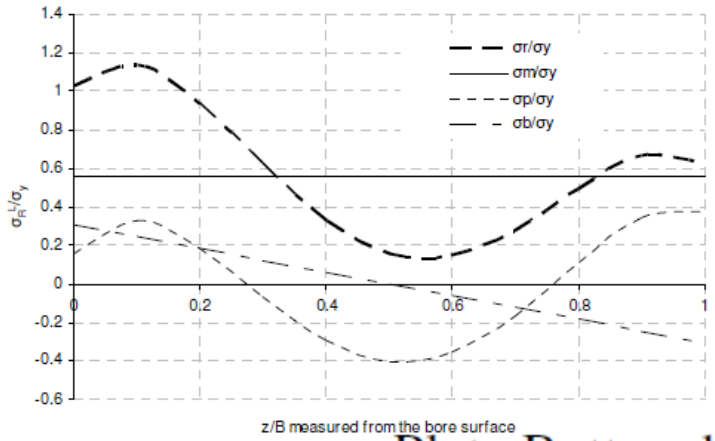
Catalogue/Compendium of Residual Stress Distributions in Welds

e.g. BS7910 Guide to methods for Assessing the Acceptability of Flaws in Metallic Structures" **BUT ONLY SOME WELDS**

A typical **upper bound** distribution through the thickness for ferritic steels

$$\frac{\sigma_R^L}{\sigma_Y} = \left[1.025 + 3.478\left(\frac{z}{B}\right) - 27.861\left(\frac{z}{B}\right)^2 + 45.788\left(\frac{z}{B}\right)^3 - 21.799\left(\frac{z}{B}\right)^4\right]$$





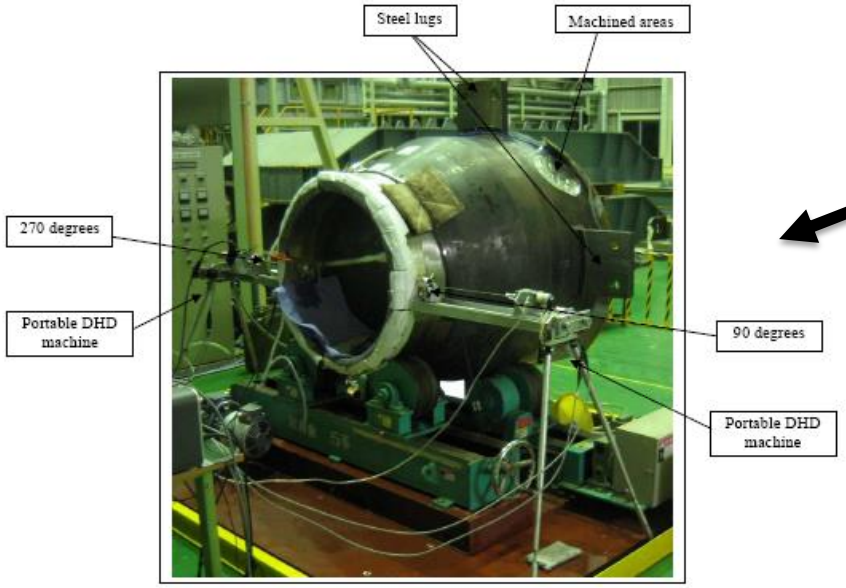
If NOT your material or weld

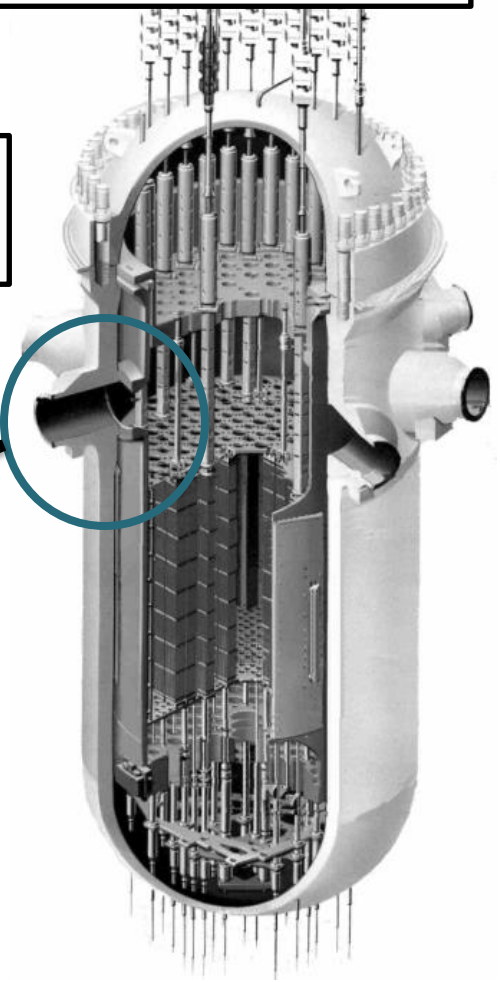
THEN MEASURE!

- Plate Butt and Pipe Seam Welds
- Pipe Butt Welds
- T-Butt Welds (Plate to Plate)
- T-Butt Welds (Tubular/Pipe)
- Repair Welds

Measurement of residual stresses in nuclear components

THERE IS NO CATALOGUE FOR THESE COMPONENTS





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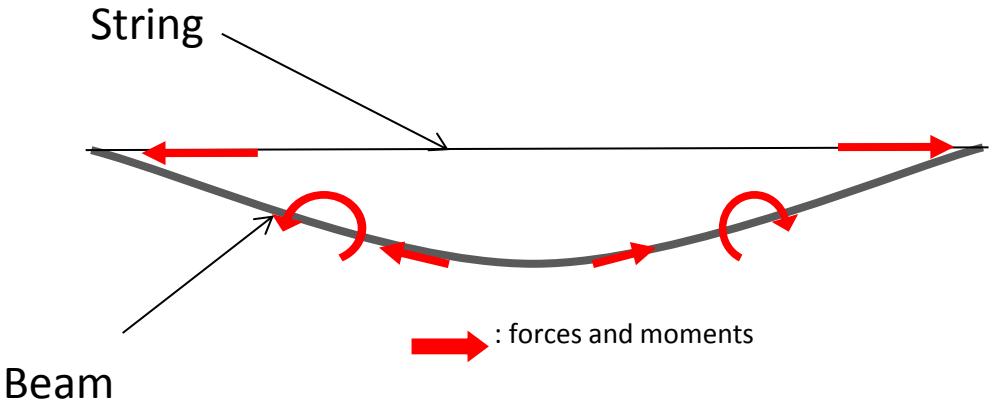
Residual Stress Experts

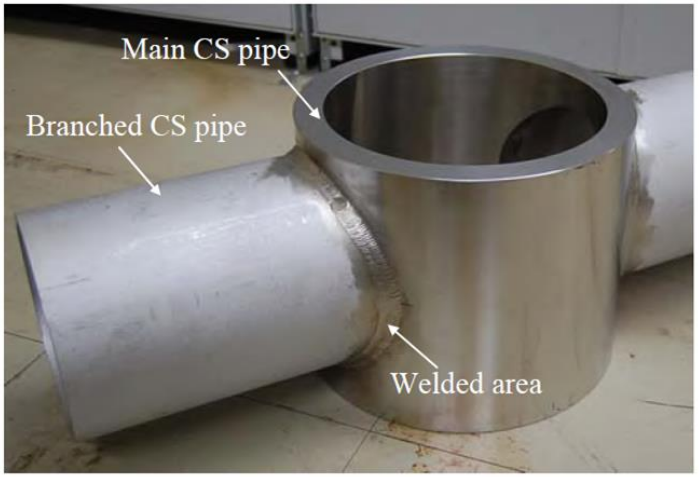
Residual stress measurement:

why, when**, where** and how?

Initial locked-in stress

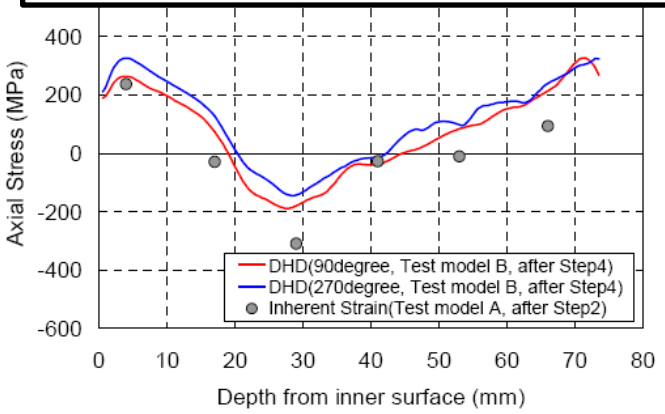


Where would you measure?



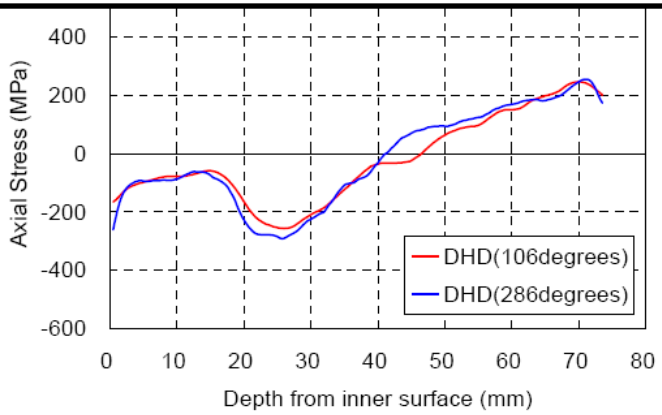
Where would you measure?

Measurement permits us to determine the through-thickness magnitudes and distributions but in limited locations

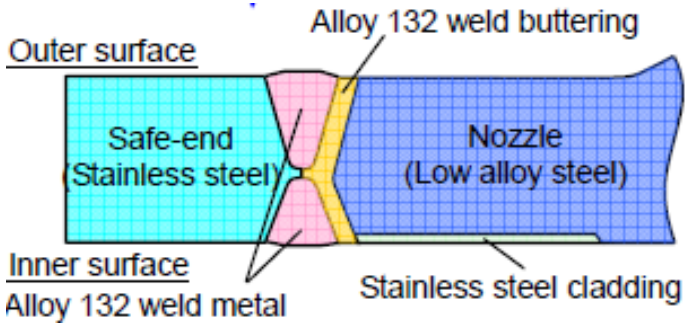


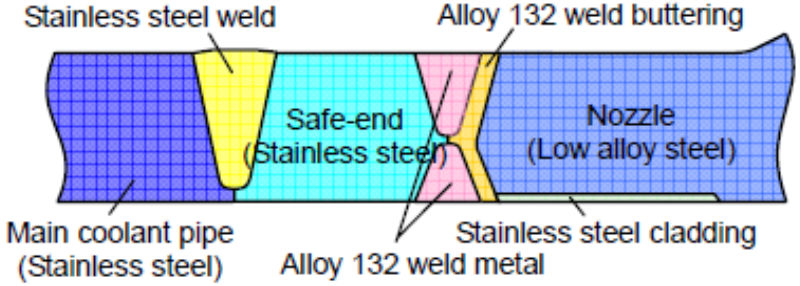
DHDs 1 & 2

Extra section



DHDs 3 & 4





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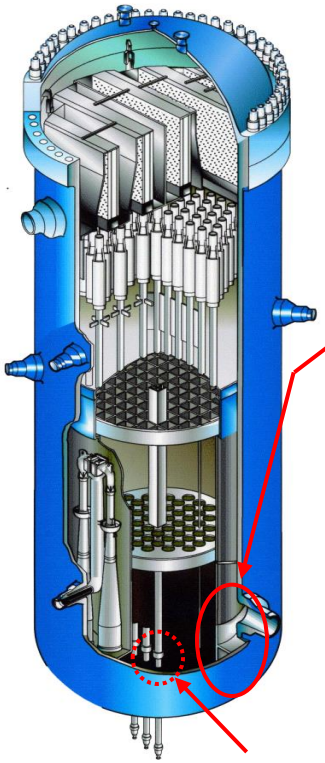
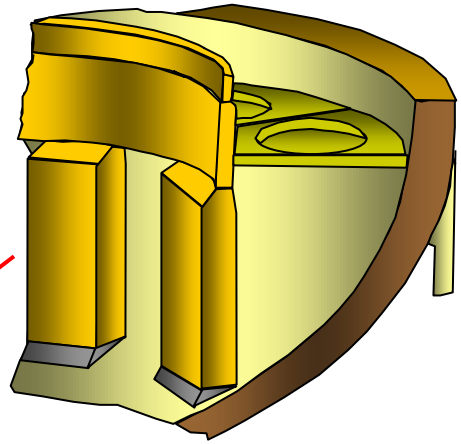
Shroud support mock-up





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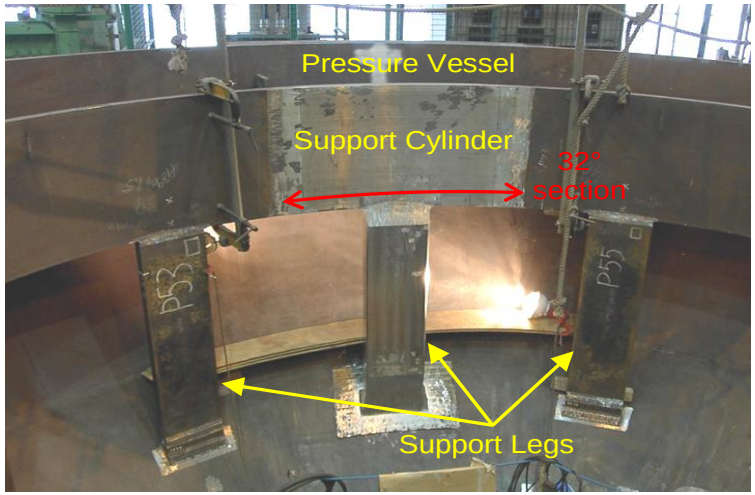
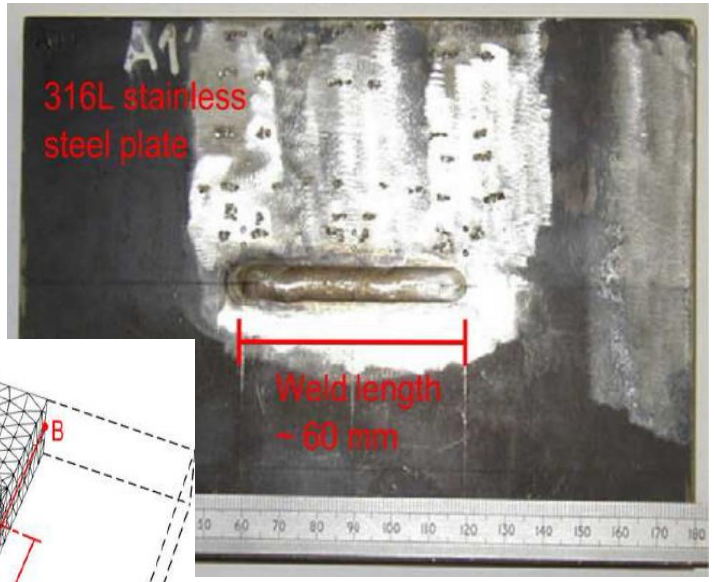
Boiling-water reactor (BWR)

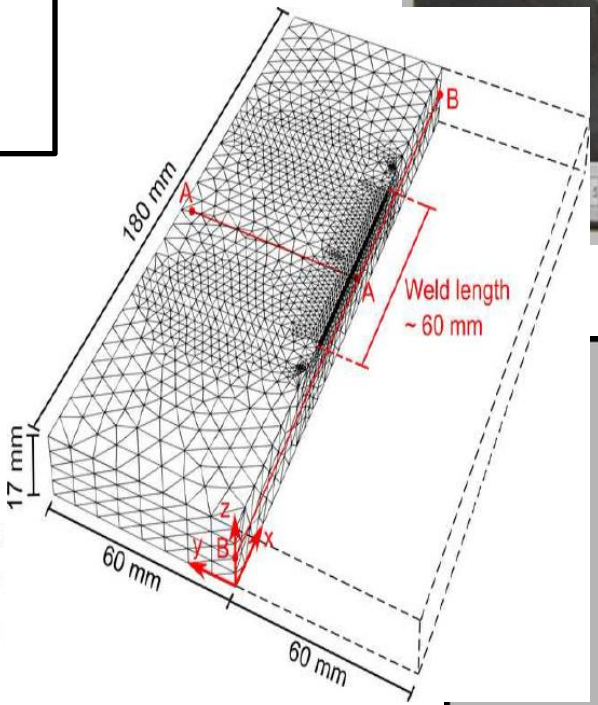


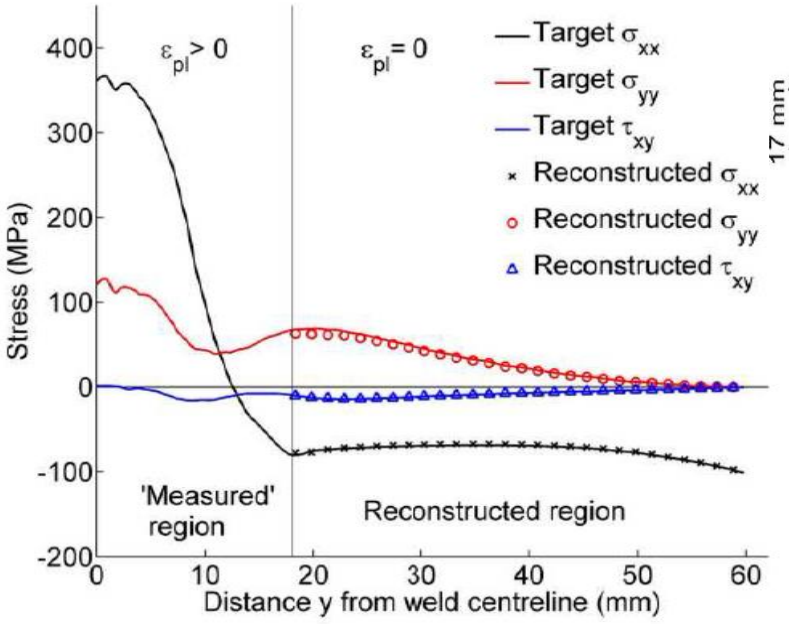
Hot off the press!

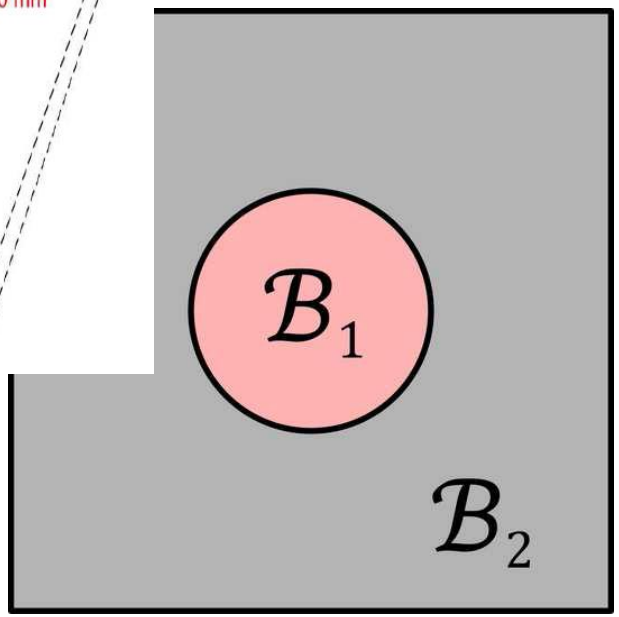
<u>Residual stress reconstruction</u>-we don't have to measure everywhere.

Just only where the misfit was created.



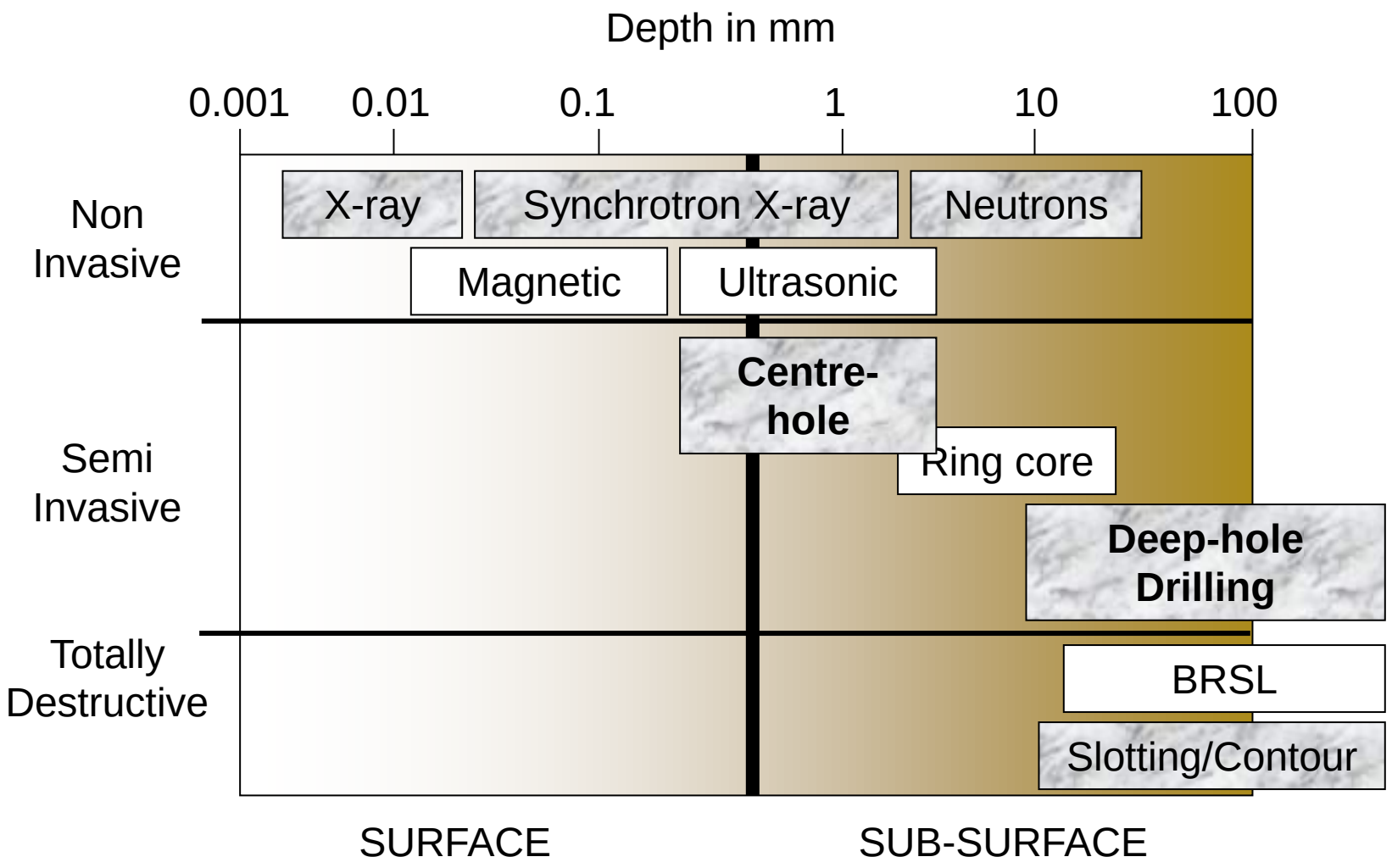






Residual stress measurement:

why, when, where and **how?**



Stress Measurement Technologies

Many techniques can be applied and using more than one is ESSENTIAL

Depth in mm

0.001 0.01 0.1 1 10 100

Boiler tubes

Non Invasive

X-ray

Synchrotron X-ray

Neutrons

Magnetic

Ultrasonic

Centre-hole

Ring cor

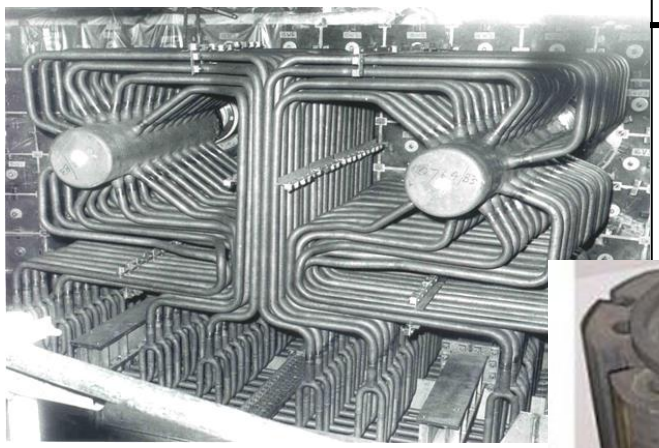
Deep-hole Drilling

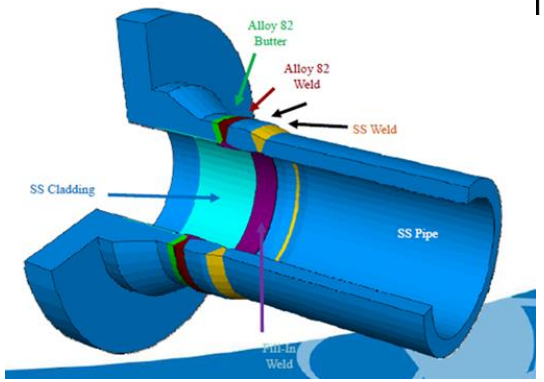
BRSL

Slotting/Contou r

CE

SUB-SURFACE





AGR Graphite Brick

PWR Nozzle

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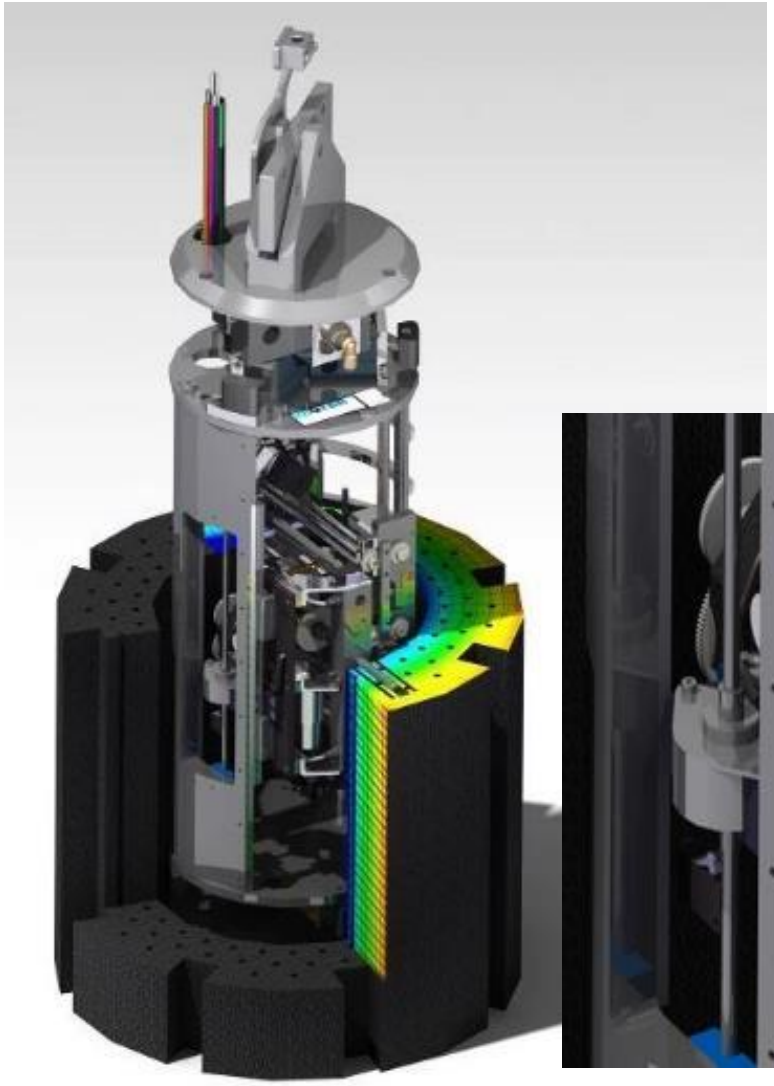

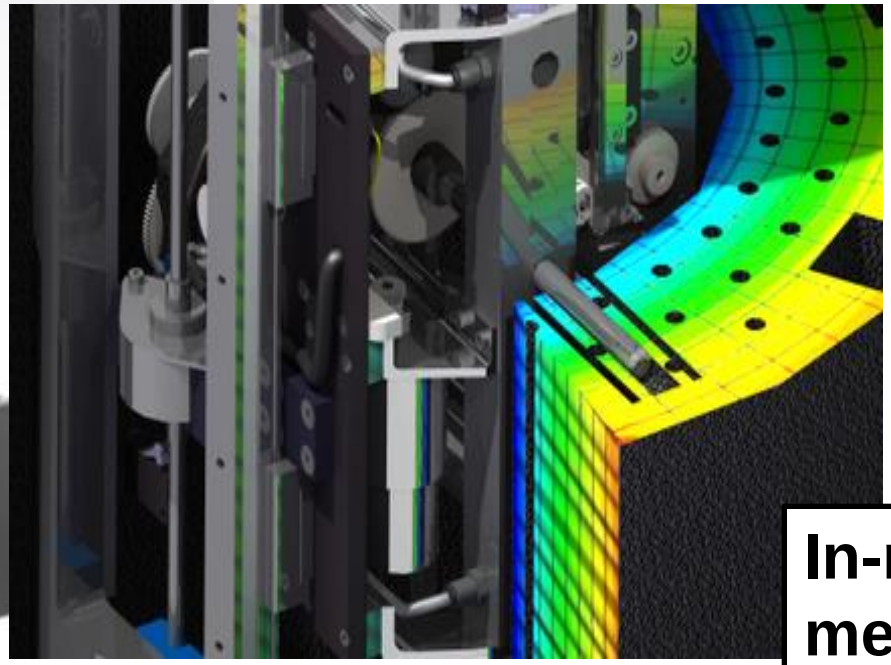

In-reactor measurement of residual stress in graphite bricks

Often you have to be innovative!

To conclude:

Think: Structural Integrity applied to LONGBOWS

Residual stress measurement:

Why: residual stress is a potential driving force for failure but not always. Therefore understand the mode of failure.

When: if there is no available information then measure but earlier work (e.g. catalogues) may give a guide.

Where: preferably in locations where the original misfit was created, e.g. in the weld

How: select several measurement technologies, choosing one is not wise!

Structural Performance of Nuclear Energy Systems

Research Chair

2012-2017

PURPOSE

- Expand and enhance Structural Integrity activities at Bristol
- Explore and extend fundamental understanding of structural performance