Business from technology

Pneumatically powered material testing devices for the extreme test conditions

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Advancing Materials testing in Hydrogen Gas

Sandia National Laboratories

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Our strategy: Materials performance in simulated extreme conditions, real failure mechanism with real stressors in real environment.

VTT Materials Performance Research Hall 1 in Espoo (altitude: -40m)

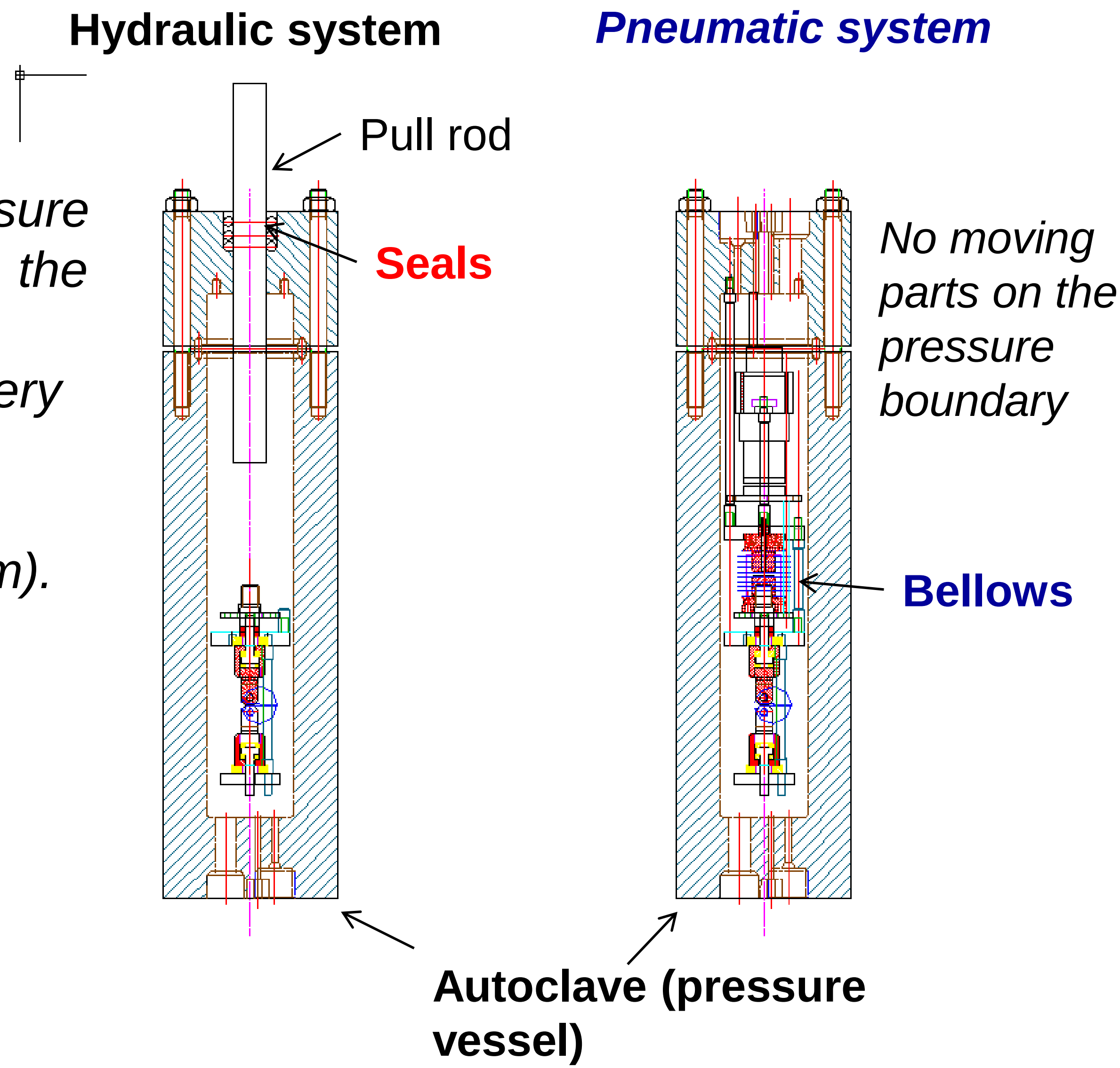
- Background
- The pneumatic servo controlled material testing system
  - **Applications and co-operators**
- In-situ tensile and fatigue tests in SCK-CEN
  - **In-situ dynamic tests vs. post irradiation tests**
- In-situ fuel cladding device, MeLoDie, CEA
  - **Stress, strain variations during the irradiation**
- Miniature size of the autoclave for SCW environment
  - **Double bellows loading apparatus, tests at LWR and SCW**
- Liquid lead testing device in JRC Petten
  - **Conceptual design for LL testing devices**
    - **On-line load monitoring system with the pneumatic double[2]bellows load apparatus**
    - **Load line displacement measurement system for crack growth measurement**

→ *Hybello Hydrogen testing system in VTT*

Background

Pneumatic system;

- *No moving parts on the pressure boundary ↔ more sensitivity, the minimal leakage.*
- *Possible to integrate into a very small test chamber.*
- *Possible to generate the test load with an inert gas (Helium).*

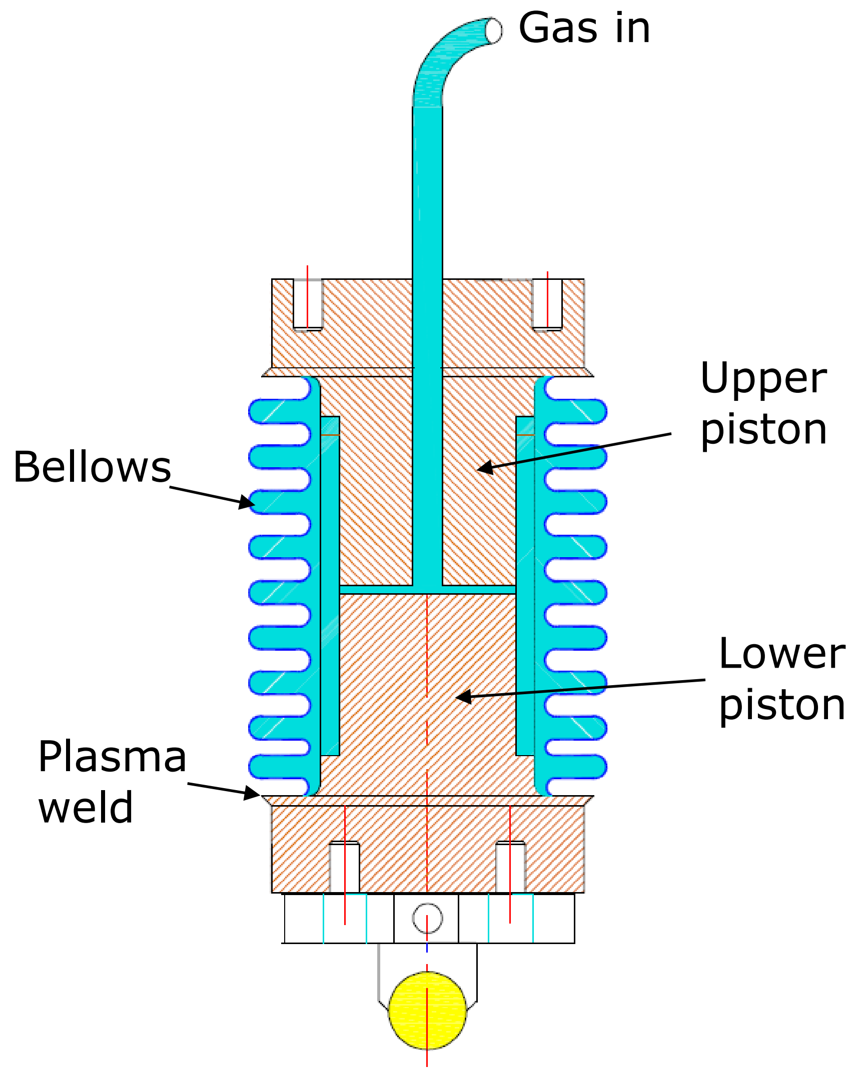


Background

The pneumatic loading unit;

- Test load generation with axial movement
- $F = p_{in}/p_{out} * A_{eff}$

- p_{in} = internal pressure
- p_{out} = external pressure
- A_{eff} = effective cross section (calibration)
- Axial movement ±2 mm
- The maximum load 50 kN
- The minimum load 100 N



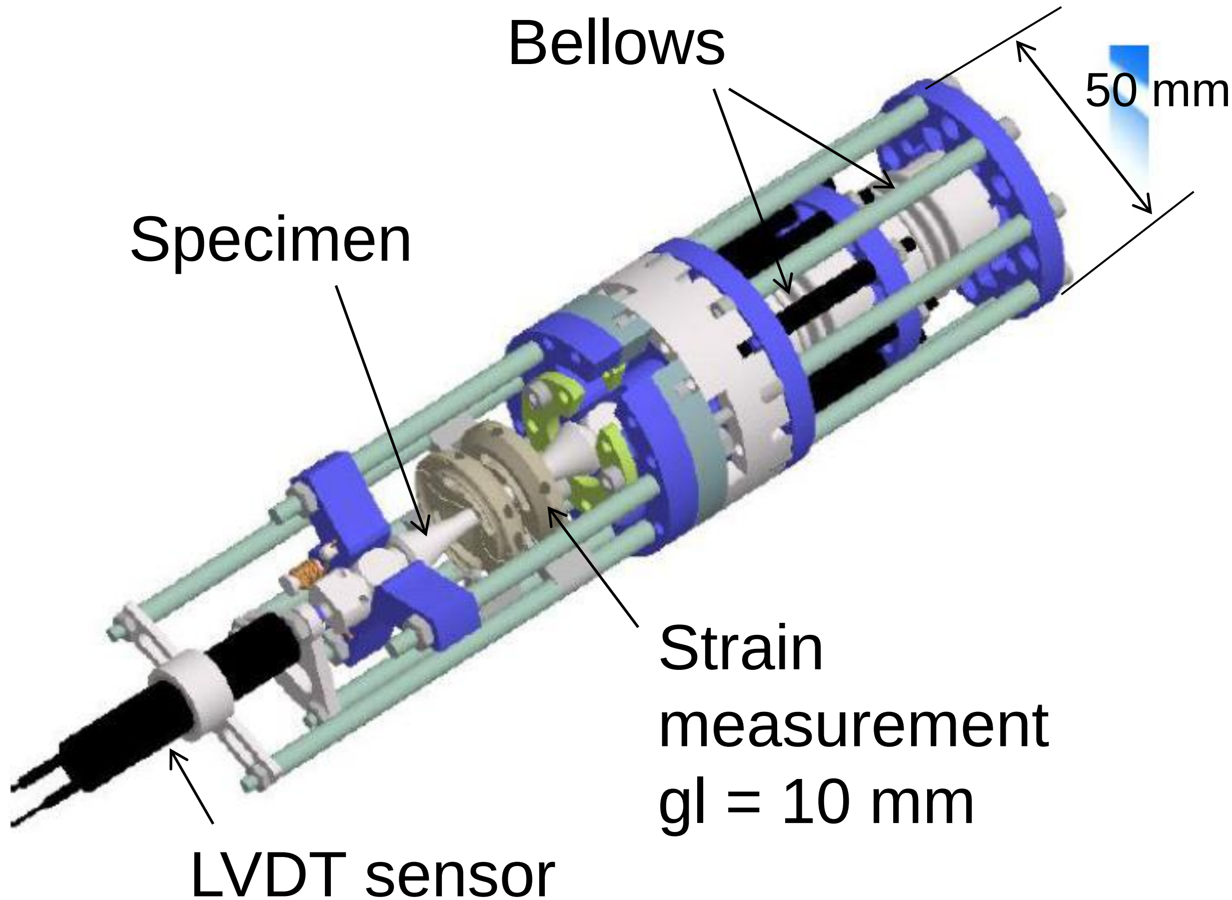
The load frame

-Support for the specimen, LVDT sensor and pneumatic loading unit

-Alignment for the specimen

-Depending on test type, specimen type and size

-In-reactor creep fatigue device

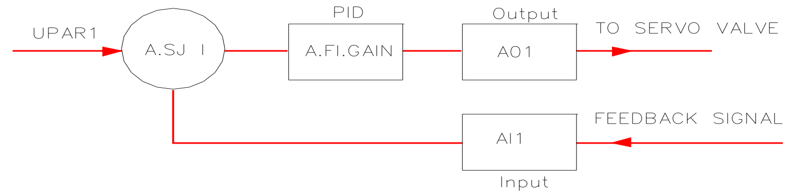


Background

Control setup

-Programmable servo controller

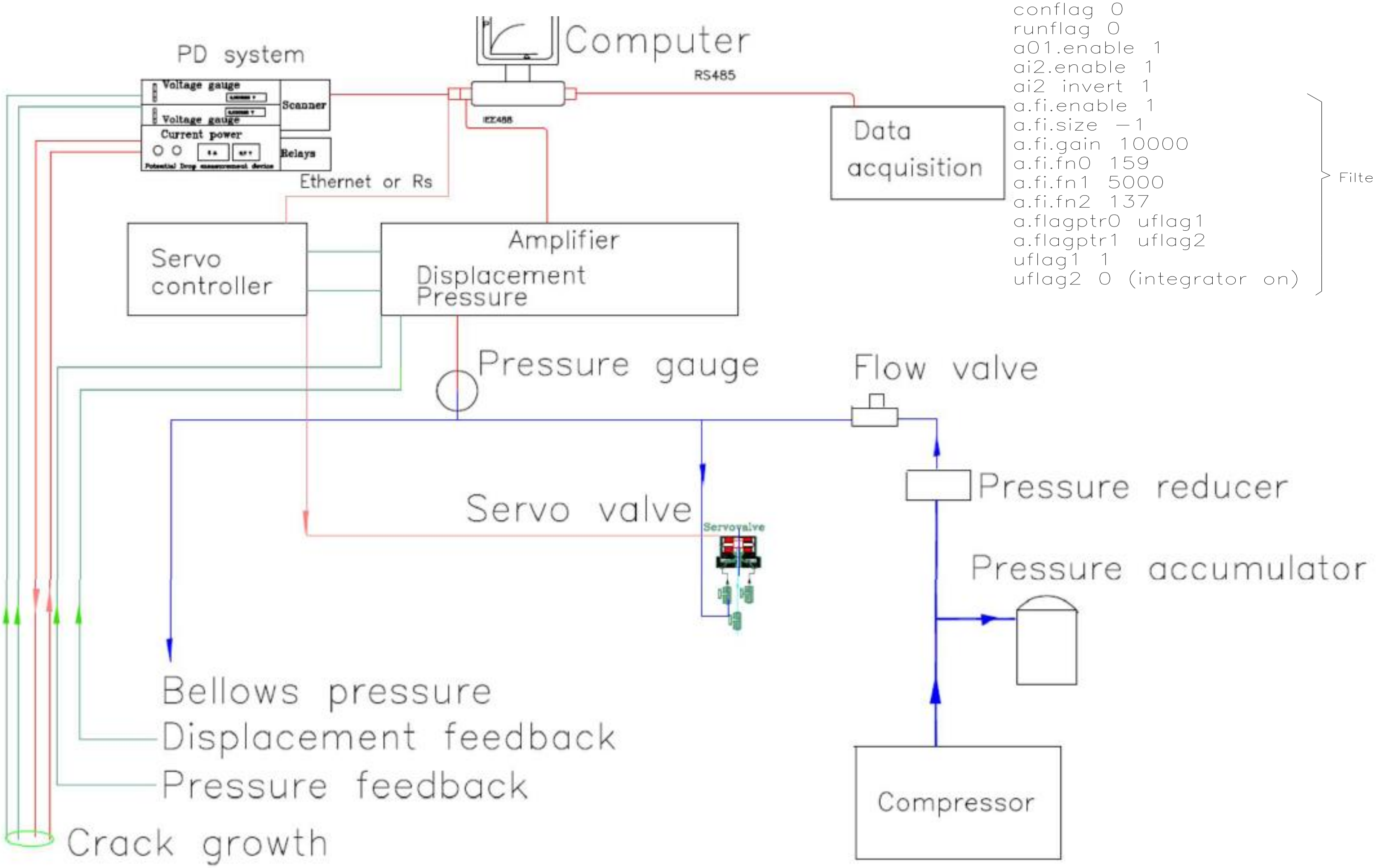
-Anolog inputs/outputs




```
conflag 0
runflag 0
a01.enable 1
ai2.enable 1
ai2 invert 1
a.fi.enable 1
a.fi.size -1
a.fi.gain 10000
a.fi.fn0 159
a.fi.fn1 5000
a.fi.fn2 137
a.flagptr0 uflag1
a.flagptr1 uflag2
uflag1 1
uflag2 0 (integrator on)
```

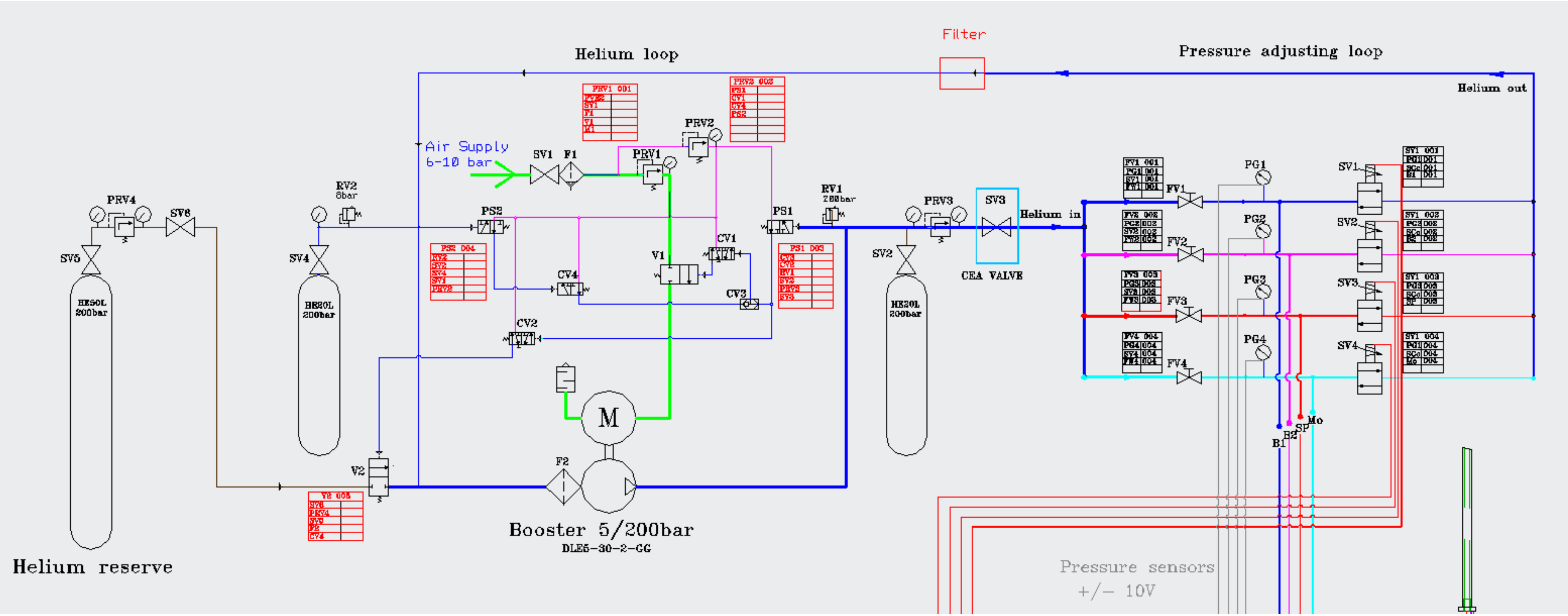
Filter

```
a.sji.enable 1
a.sji.inptr0 ai2.outvalue
a.fi.inptr a.sji.outvalue
a01.inptr a.fi.outvalue
a.sji.inptr1 upar1
timer1.enable 1
fnkey 4
timer
0
fnkey 6
timer
0
conflag 1
runflag 1
relay 1
```



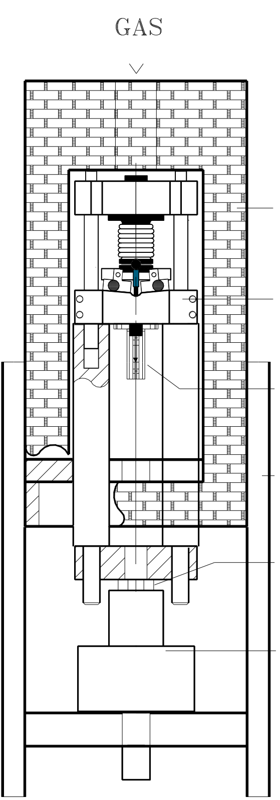
Background

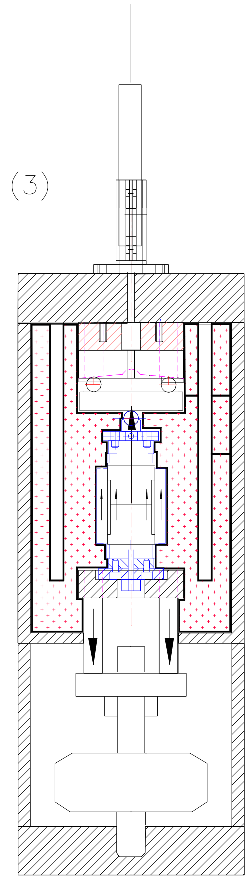
The air booster based Helium pressure adjusting loops

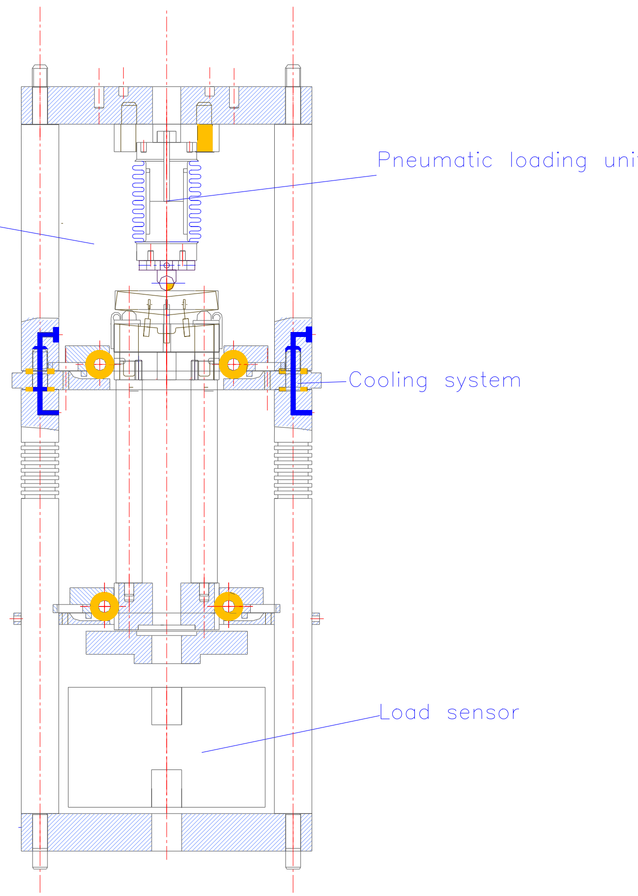


Designed for use in OSIRIS-reactor in France

Development of the calibration systems for the pneumatic loading unit







$$F = (p-p_h)*A_{eff}$$

$$\Rightarrow A_{eff} = F/ (p-p_h)$$

F = load [N]

p = pressure [MPa]

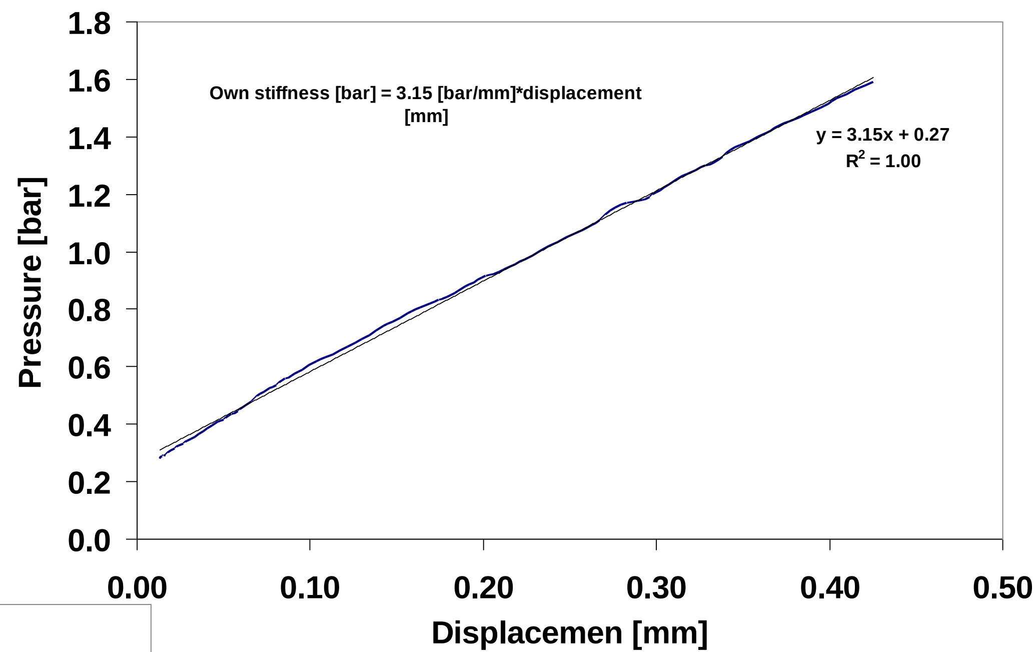
p_h = pressure loss [MPa]

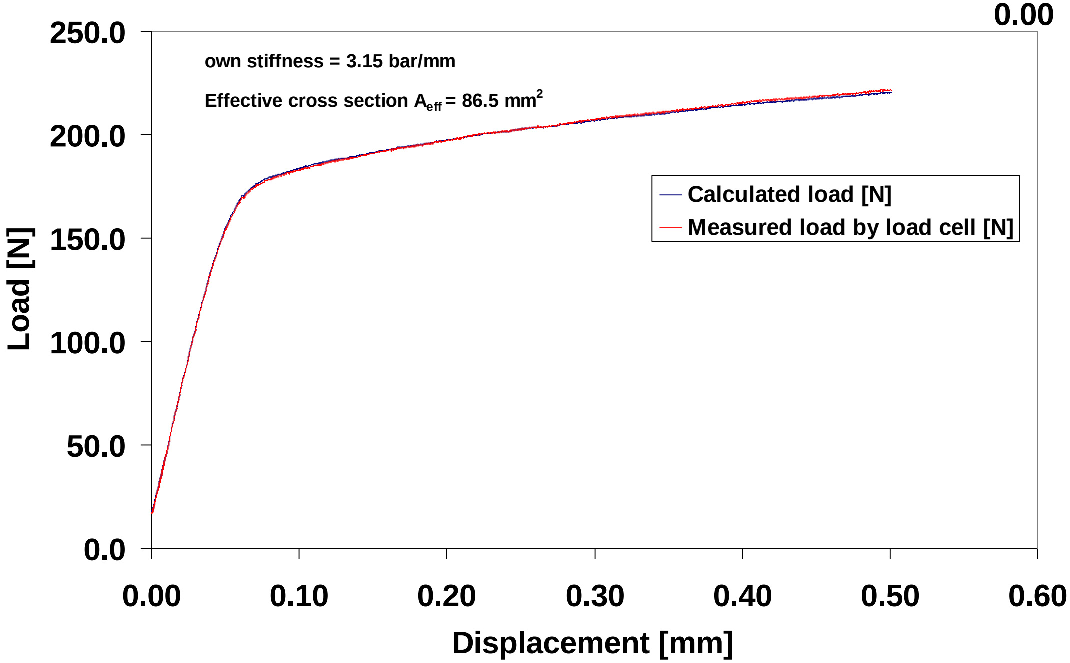
A_{eff} = effective cross section of the bellows

Background

1. *Determination of the own stiffness of the bellows*

OS = 3.15 bar/mm





2. *Determination of the effective cross section for the bellows*

$A_{eff} = 86.5\ mm^2$

In-reactor experiment 2000-2007

The pneumatic tensile test modules which were designed and constructed at VTT have been installed in the BR-2 reactor at SCK-CEN, Belgium.

First unique experiments i.e., strain-controlled tensile experiments using OFHC-Cu have been carried out in-situ under neutron irradiation.

Irradiation conditions:

BR-2 position G60

reactor pool water at 90^{o}C

neutron flux ~0.3 x 10^{14} n $cm^{-2}s^{-1}$ (E>1 MeV)

damage rate ~2 x 10^{-4} dpa h^{-1}

Loading conditions:

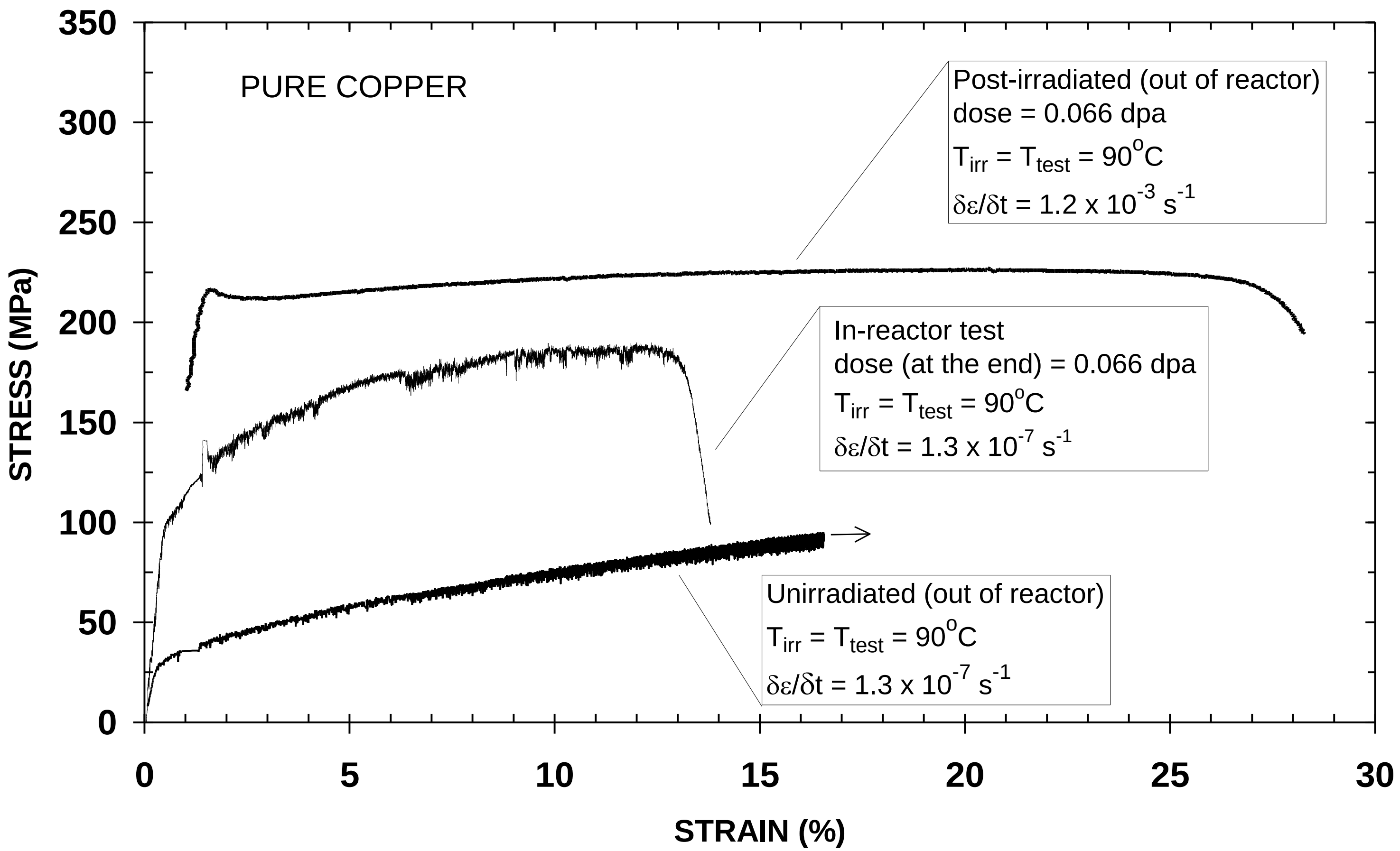
uniaxial tensile test

strain controlled

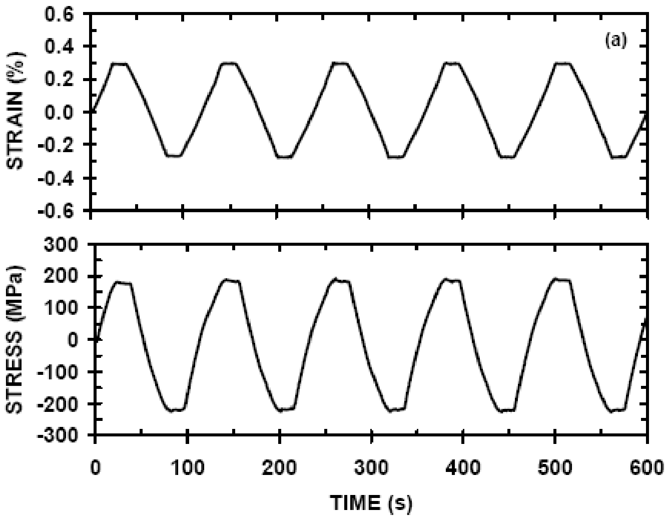
strain rate ~10^{-7} s^{-1}

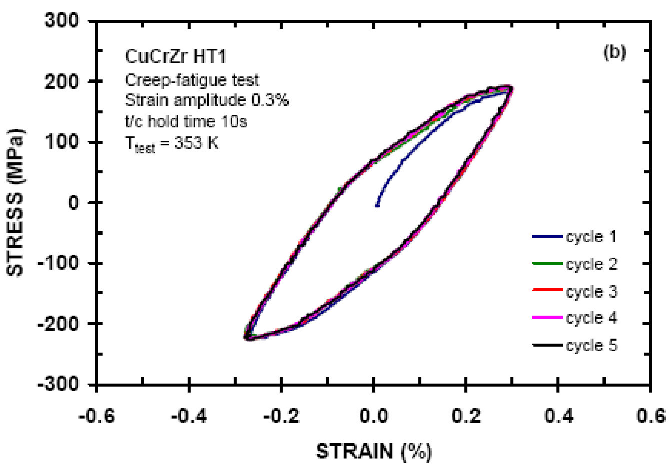
European Fusion Technology Programme: VTT, Risø, SCK-CEN

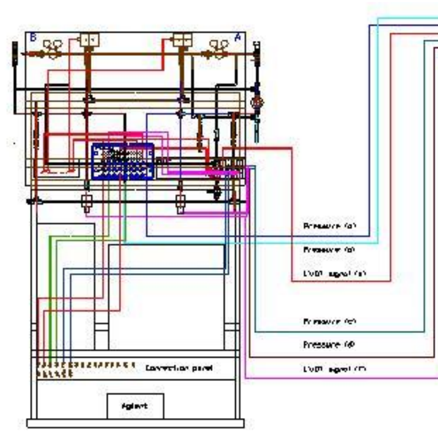
The dynamic response of a tensile specimens during un-irradiated, post-irradiated and in-reactor experiences

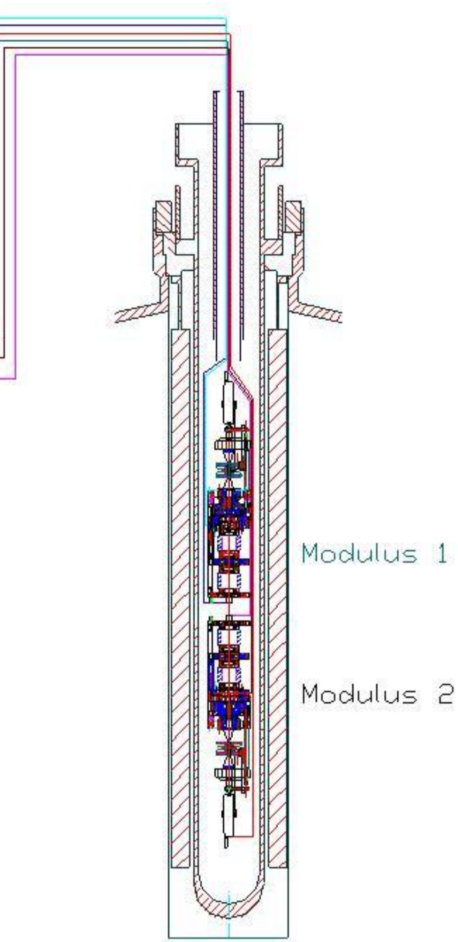


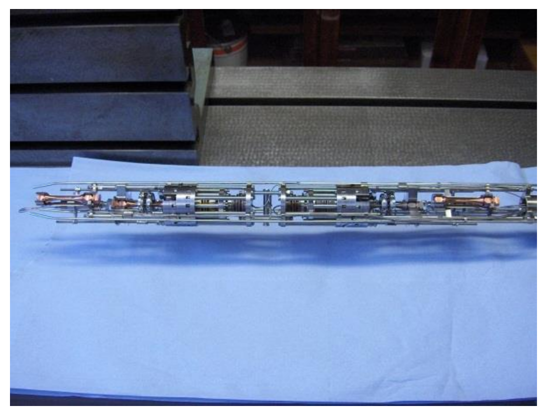
In-core creep fatigue testing device









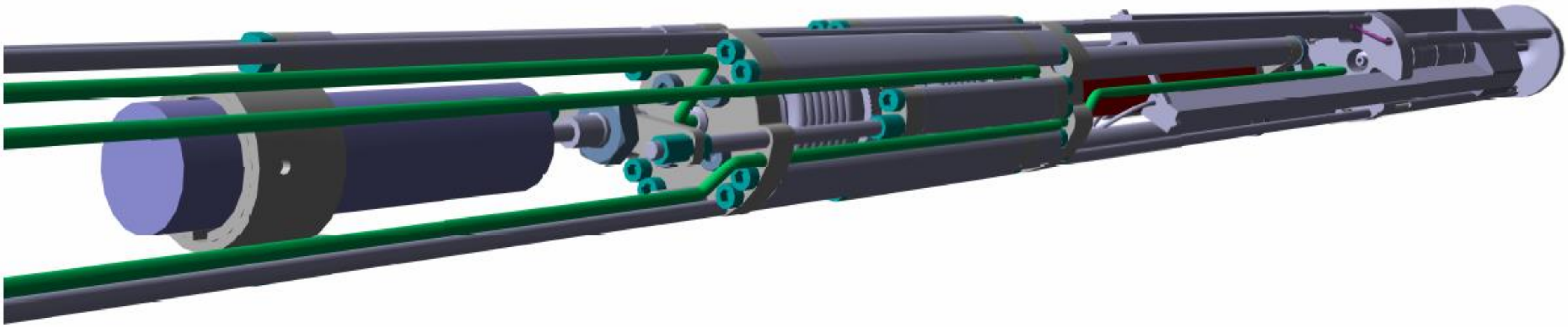


Tests carried out at Mol test reactor BR-2 in 2003-2005

In-core multi-axial creep test device

- VTT CEA in-kind project
- Bi-axial loading; push and pull bellows
- Tubular pressurized specimen
- Constant load tests with axial strain/hoop strain sweeps
- He-re-circulation loop

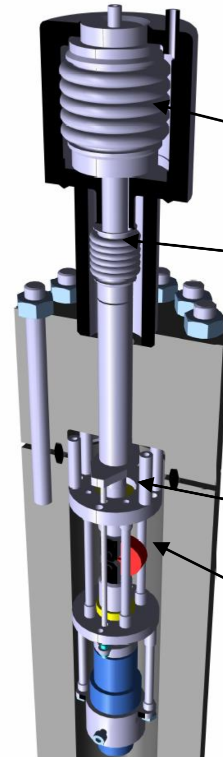
Osiris test reactor (CEA)

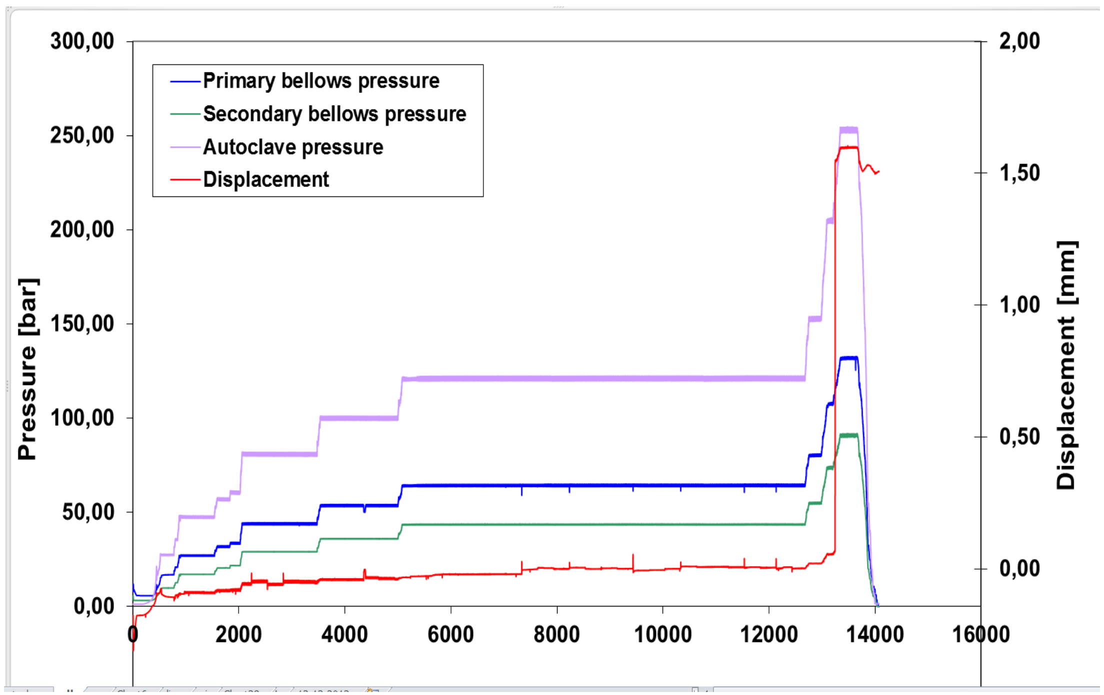


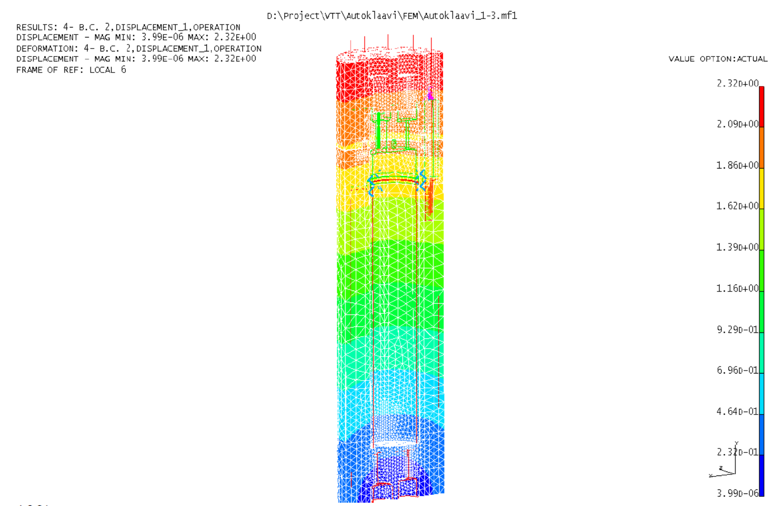
First irradiation (OSIRIS-reactor, France) in 2013

Miniature size crack growth rate testing device

- **Developed together with VTT, Finland and JRC Petten, The Netherlands (2005…on going)**
- **Supercritical water (SCW) environment: 650 °C and 350 bar**
- **Autoclave outer diameter: 64 mm**
- **Autoclave inner diameter: 32 mm**
- **The maximum load: ~±3 kN**
- **Displacement range ± 1 mm**
- **Test types: Constant load, rising load, fatigue**

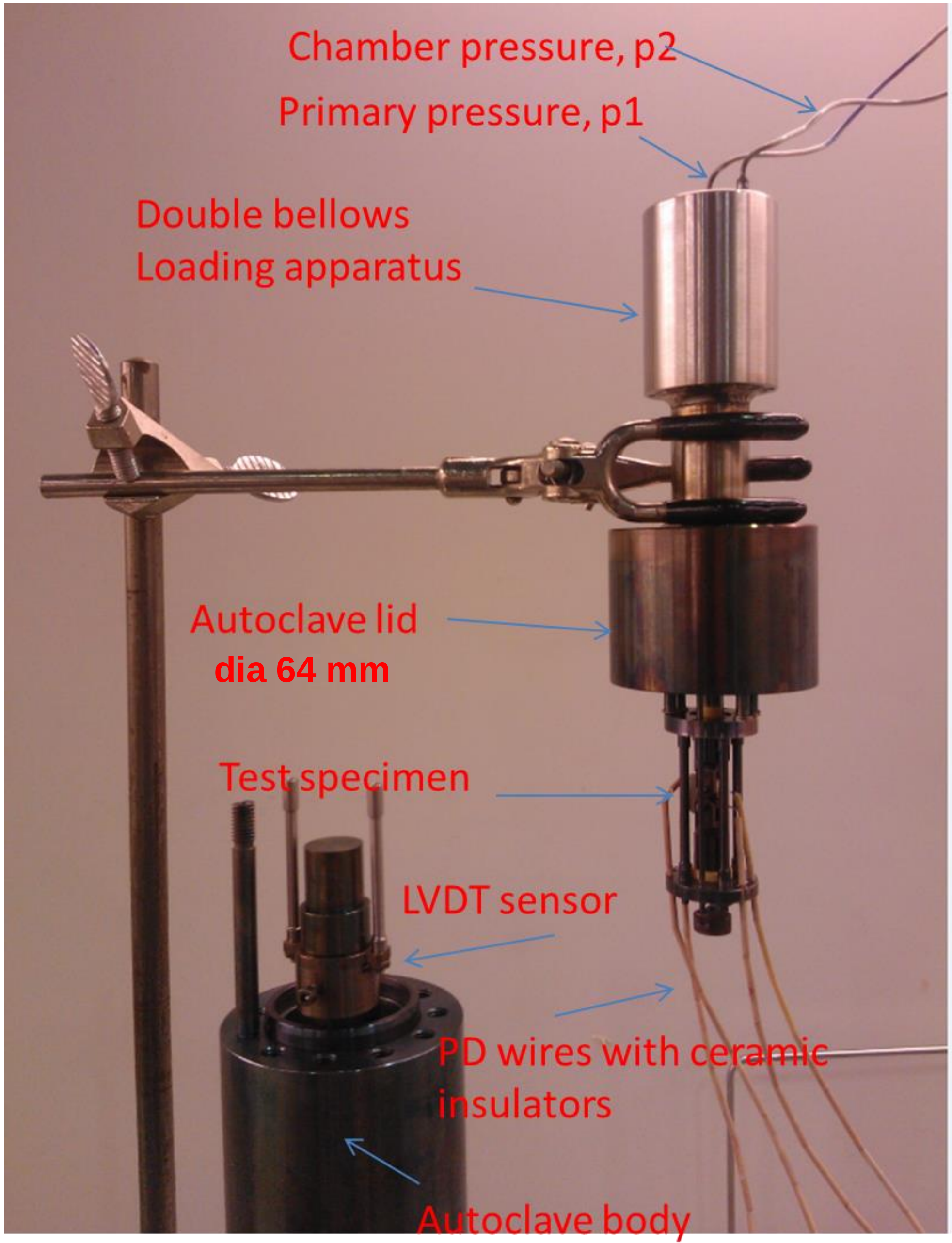






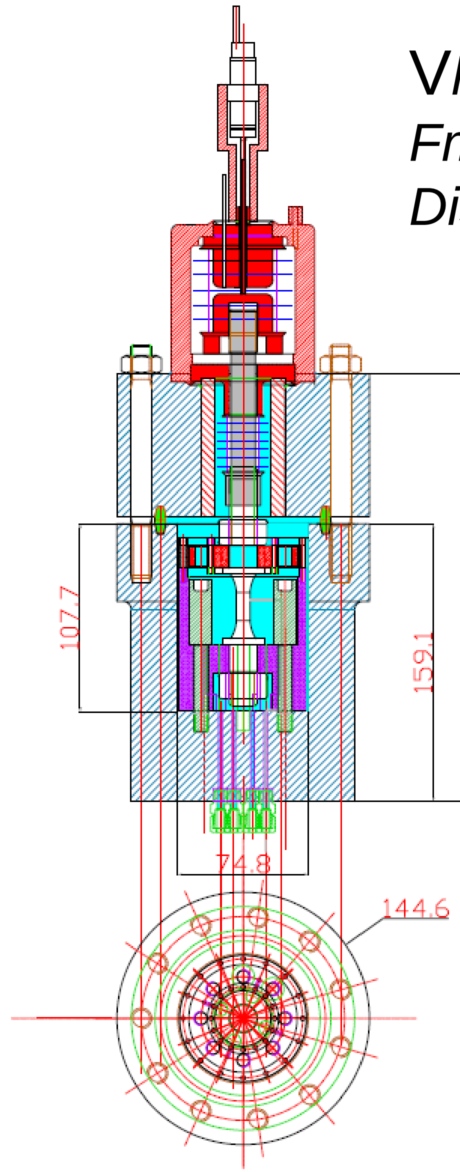
Miniature size crack growth rate testing device

- *SCW environment*
- *Double bellows loading apparatus*
- *Test set-up for the crack growth test with 5 mm DC(T) specimen under SCW coolant conditions*



VTT-HyBello: pneumatically powered test device for hydrogen gas, ready in 2013

Vhyd~0.2 dl
Fmax ~ 30 kN
Disp ~ +/-2 mm



Target test:
Specimen: 7≤Ø≤8mm
Drilled: 100≤Ø≤500µm
N_f criterium: Crack~500µm
Instrumentation: Δa/ΔN

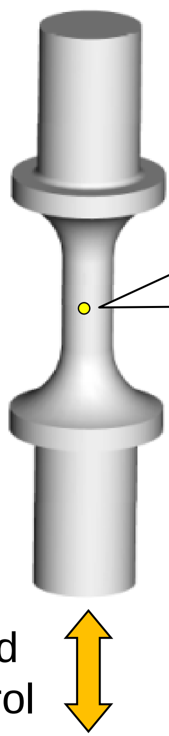
Target Equipment:
H_2: ≤350bar,≤100°C
Axial loading: ±30kN (~1%)
Internal load train: 2 bellows
Frictionless load: Δp (p123)
Medium: air, He or water
Frequency: LCF -> HCF

Safety concern:
Vessel volume: ≤0.5 liter
H_2 volume: << 0.5 liter
Infra: 220V, gas supply -> find safe place/H_2 leaks, water pool?

VTT-HyBello: pneumatically powered test device for hydrogen gas, ready in 2013

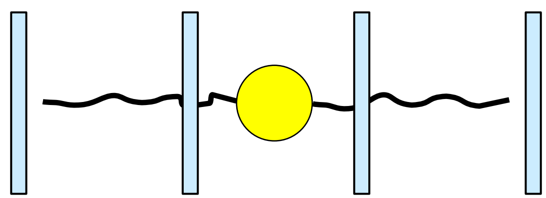
Target in EU project MATHRYCE:

Specimen:	7≤Ø≤8mm
Drilled notch:	100≤Ø≤500µm
N_f criterium:	crack a~500µm
To measure:	Δa/ΔN

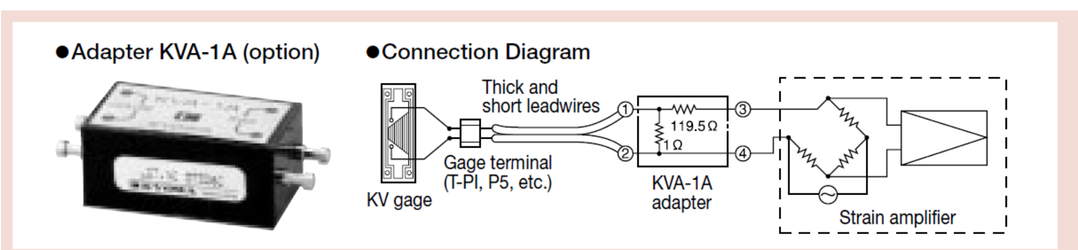


Load control

”on specimen” manufactured crack gages ~ nanotechnology



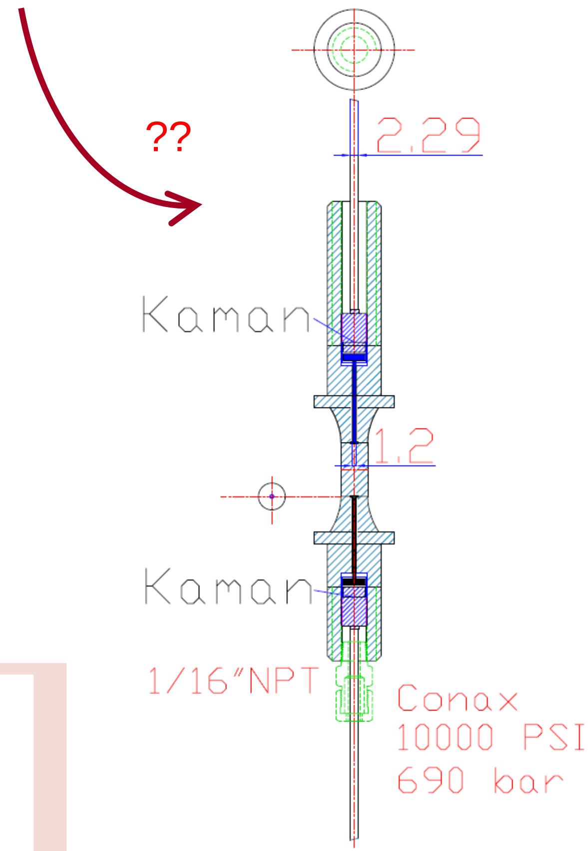
Millimeter scale crack gages ~ same idea:



Some day ?

Strain controlled LCF tests:

- Cyclic stress strain response (CSS)
- ASME III type desing curve

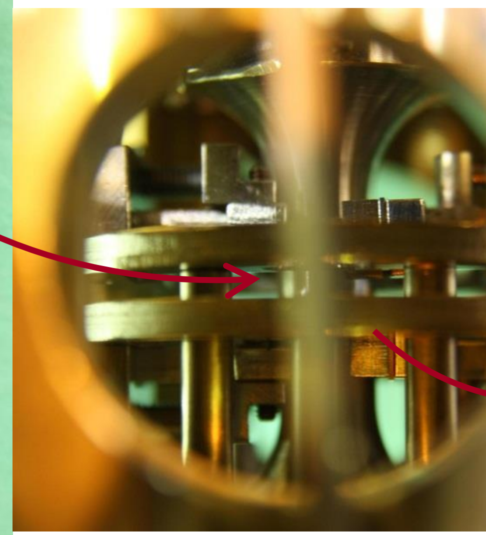


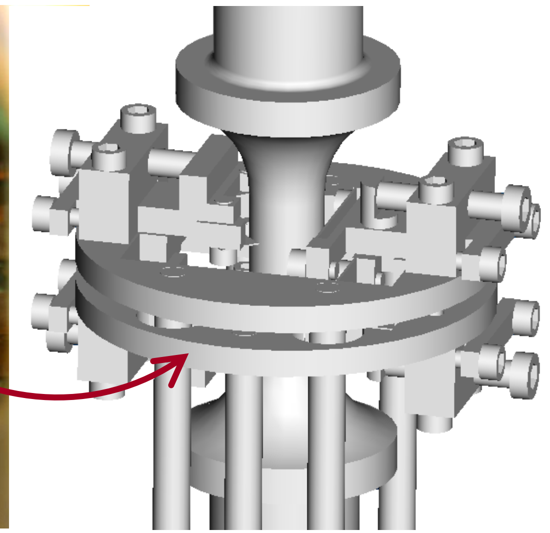
FABELLO – for LCF

FABELLO for ϕ 8 mm
DIRECT STRAIN CONTROL

→ ASTM E 606
valid LCF data
in 135 bar
325 ºC water

(Results in)
(PVP 2013)



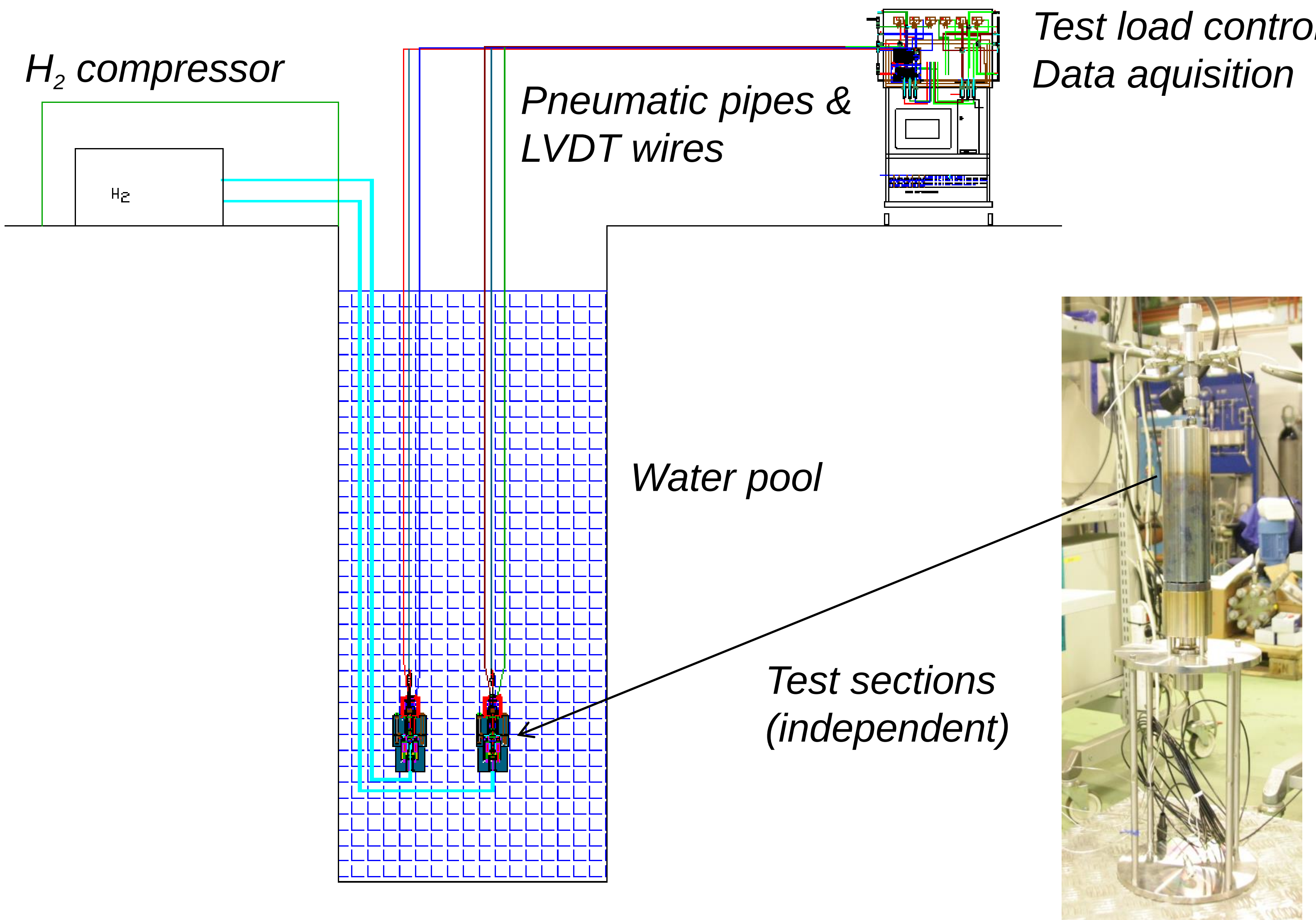


This in 1000 bar Hydrogen ≈ ??

Safety concerns and open questions

- Amount of H_2 gas in the test section:
  Possible solution: the minimum volume of the H_2 vessel and small size pressure tubes; D_{out} = 1.6 mm D_{in} = 0.7 mm
- *Leakage of H_2:*
  Possible solution: Water pool, safe test environment + Leagage detectors -> ventilation of the test room
- The strain measurement system (electrical power is needed for the LVDT sensor or strain gauges) -> sparking?
  Possible solution: place the LVDT sensor outside from the H_2 test section
- Sealing of the autoclave and needed feedthroughs:
- *Solution: Double coinical metal rign sealing, Conax or Swagelok type of the standard connectors for the wires.*
- Material selection (alloy 625), coating, welding etc…

Illustration for the H2 test set-up



High precision Pneumatic material testing technology

- *No moving parts on pressure boundary*
- *Patented pneumatic servo controlled pressure adjusting loop*
  $\Rightarrow$ *more sensitivity, more flexibility*
- *Easy to move and integrate into different test environments*
  - *Autoclave testing at laboratory*
  - *Tensile/fatigue tests inside the test reactor core with 35 m pipe lines*
- *Possible to test many specimens at the same time*
- *Possible to test with inert gas (Helium)* $\Rightarrow$ *no pollution problems for the test environment*
- *Pneumatic double^{2}bellows load apparatus -> direct load measurement under high temperature and pressurized test environments*