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EXPERIMENTAL MATERIAL IRRADIATION IN THE JULES HOROWITZ REACTOR

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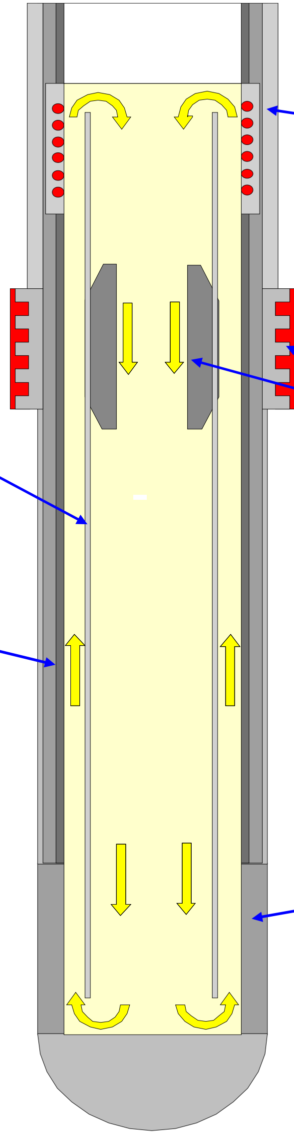
Outline

- Presentation of the material test device for large flux and low gradients

- Sample holder for controlled biaxial stress experiment

Device for large fast flux and small gradients

Picture without sample holder



Heating zone:
- electric furnaces
- good thermal insulation between inside of the device and water of the core

Tube to separate the hot channel from the cold one

Electromagnetic pump for creating a stream of Sodium-Potassium alloy inside of the device

Gas gap (thermal insulation)

Cooling zone (Exchanger between NaK and cooling water of the core):
- area far away from neutron and gamma flux
- high conductivity between device and cooling water of the core

From classical device to new device concept

Classical irradiation device

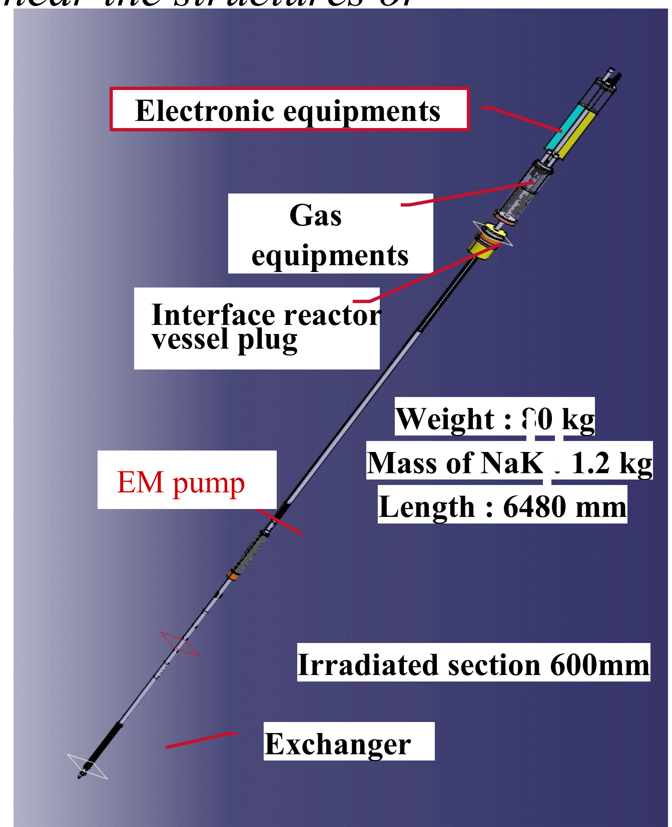
- ✓ Heat removal only by radial conduction in NaK
  - ☞ *High thermal gradient inside of the specimen*
  - ☞ *Important local variation of temperature on specimens near the structures or when touching them*

  OK when reasonable gamma heating

  But not in the core of JHR

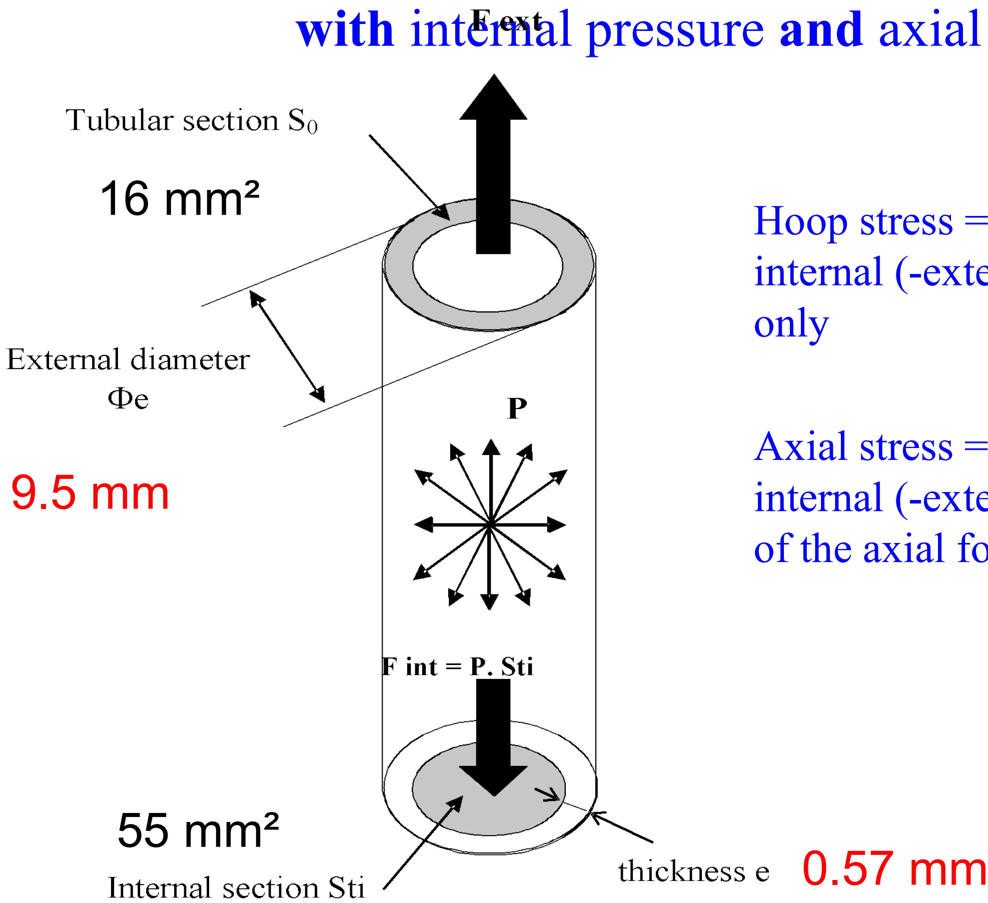
Getting small gradients & large damage

- ✓ Forced convection of sodium-potassium alloy by the use of an electromagnetic pump, adapted to the size of the device.
  - ☞ *NaK temperature 250°C to 600°C*
  - ☞ *NaK flow rate $1 m^3/h$ to $2 m^3/h$ (pressure 2 bar)*
  - ☞ *Electromagnetic pump power ~2.5kW*
  - ☞ *Total electric power ~36kW*



Typical example of current needs
For a better knowledge of mechanical behavior under flux, testing samples with different biaxiality ratios (Zr cladding : Anisotropic and textured)

- Tubular samples **(PWR cladding, other specimens with similar dimensions) with** internal pressure **and** axial Force **(tension/compression)**



Hoop stress = function of the internal (-external) pressure only

Axial stress = function of the internal (-external) pressure <u>and</u> of the axial force

Mean stresses

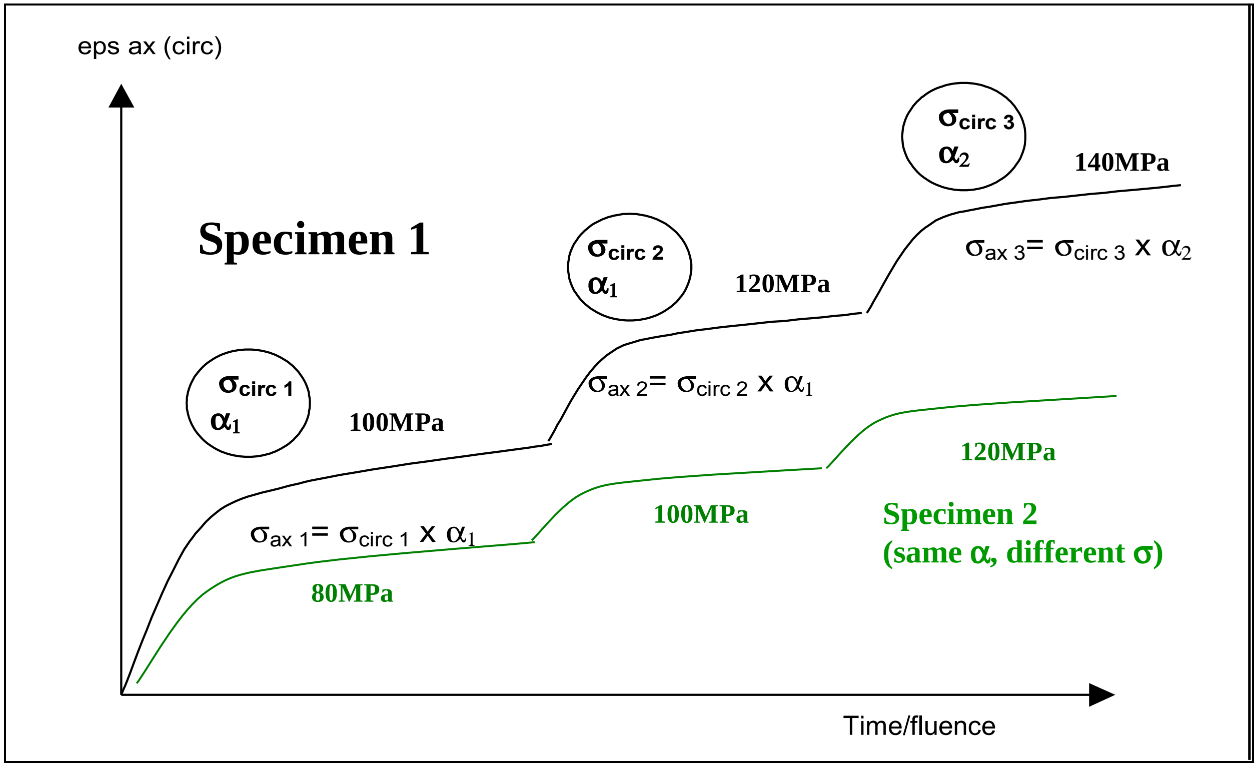
$$\begin{cases} \sigma_\theta = P.\dfrac{\phi_e - 2e}{2e} \\ \sigma_z = \dfrac{P.Sti + Fext}{S_0} \end{cases}$$

Biaxiality ratio $\alpha = \dfrac{\sigma_z}{\sigma_\theta}$

$$\alpha = \frac{1}{2}\left[\frac{1 + \dfrac{F_{ext}}{P \cdot S_{ti}}}{1 + \dfrac{e}{\Phi_e - 2e}}\right]$$

Example of experiment to be performed

Irradiation Creep with stress increments and control of the biaxiality ratio



If several specimens in series (stressed and unstressed) :

•**Different initial stress** (thinned specimen) for same biaxiality ratio

•**Growth determination** **(with unstressed specimens)**

• **Effect of material evolution under irradiation** (hardening, etc…) : stress i specimen 1 = stress i+1 specimen 2

Specifications 1/2

- Specimens
  - *Tubular samples (PWR cladding, other specimens with similar dimensions) zirconium alloy*
- Stress monitoring
  - *Application of internal pressure associated to tensile (or compressive) load*
  - ***Control of the biaxiality** ratio ($\sigma_{ax}/\sigma_{circ}$).*
  - *Range of stress up to 500 MPa*
  - *Possibility of **complex loading path** : creep tests including stress increments or decrements, hold at a given strain (relaxation), …*
- Strain measurement
  - *In situ measurement*
  - *Axial and diametrical strain*
  - *Diametrical strain at different axial locations (profile)*
  - *Accuracy of strain measurements*

Specifications 2/2

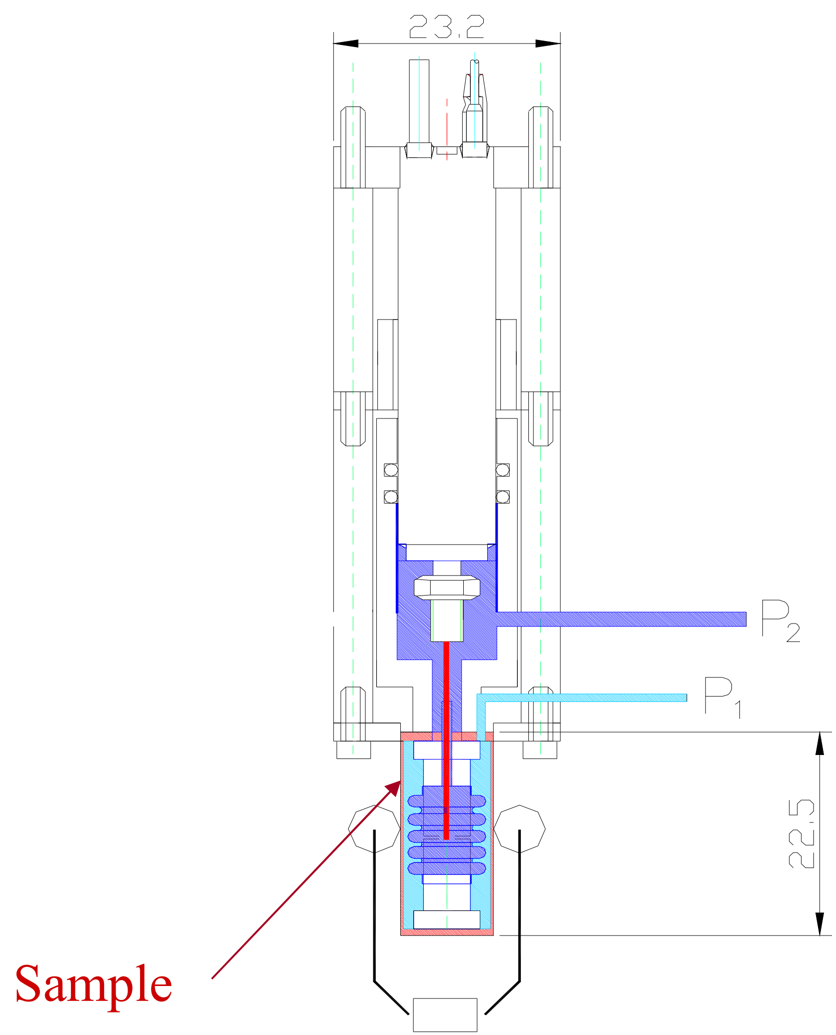
- ✓ Neutron flux (spectrum, gamma heating …)
  - ☞ *Relatively high flux requested 2 to 3 10^{14} $n.cm^{-2}.s^{-1}$ (E>1MeV)*
  - ☞ *good accuracy in final target fluence (fluence monitors counting, on-line instrumentation, ….)*
  - ☞ *Accurate dosimetry capability needed*

- ✓ Temperature control and accuracy
  - ☞ *Range of temperature 300 to 400°C*
  - ☞ *circulation of coolant to avoid thermal gradients*

Conceptual design for the sample holder

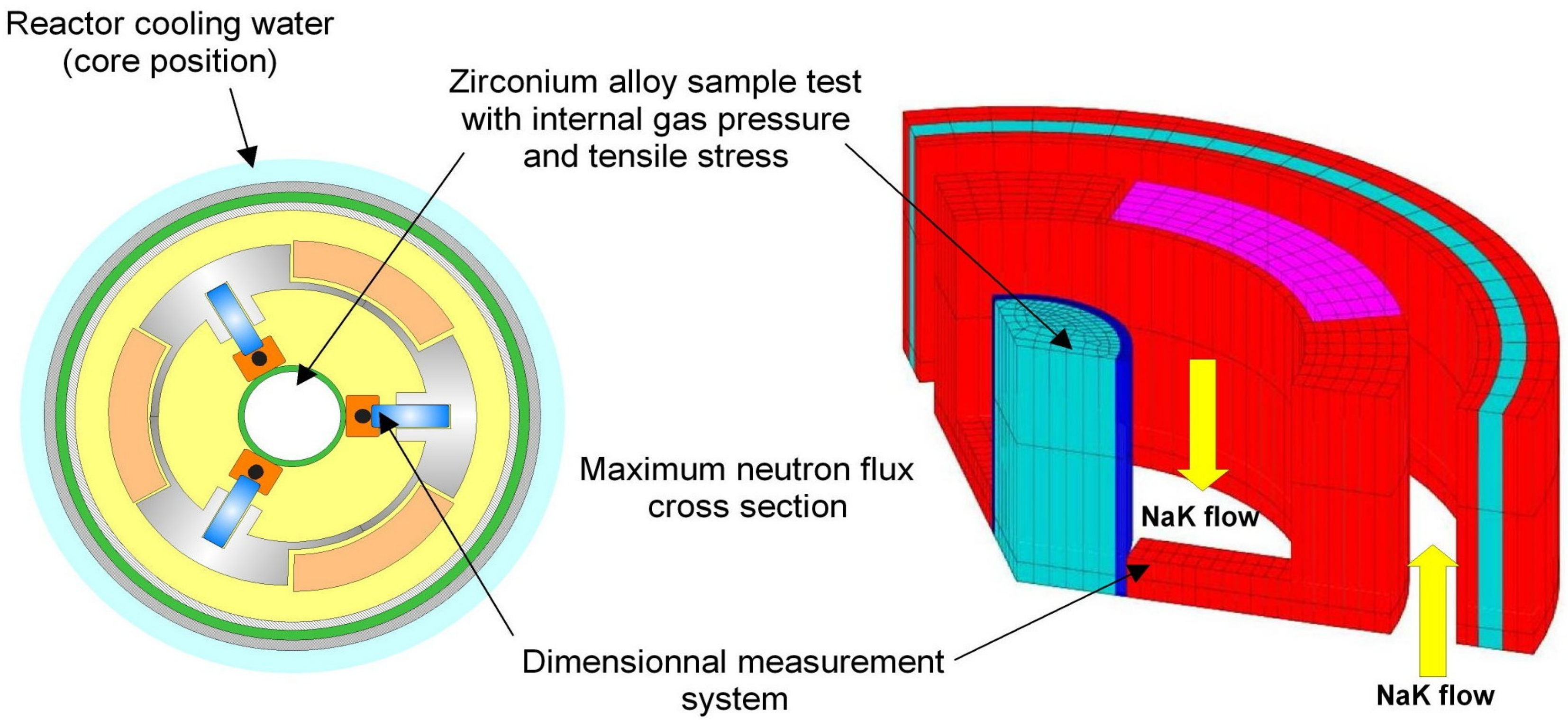
Pneumatic m

- load system l
  - ✓ Hoop stre
  - ✓ Axial stre
- Axial measu
- Diameter me LVDT (unde



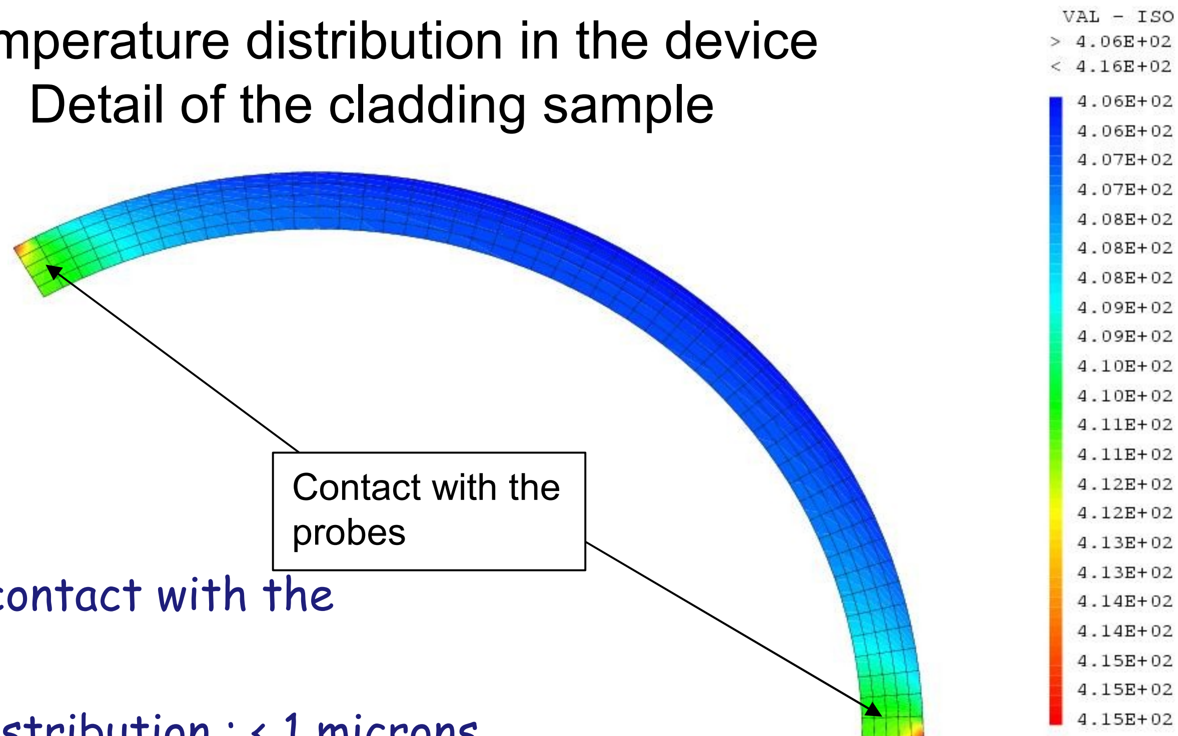
↳ Critical features: influence of the measurement system on the cladding temperature

Cladding sample irradiation temperature taking into account device conceptual design and measurement system



Thermal calculation

Temperature distribution in the device
Detail of the cladding sample



Local « hot spot » at the contact with the transducers : + 10°C

Radial Von Mises stress distribution : < 1 microns

- Acceptable influence of the measurement system on the cladding temperature
  - ✓ in regards to the very local aspect of the “hot spot” , the small strain perturbation
  - ✓ And taking into account axial displacement of probes

Conclusions

- Major challenge of controlling temperature and limiting gradient under large flux will be addressed by the use of a NaK pump.

- To assess the behavior of anisotropic textured material there is a need for biaxial state experiments
  - ✓ Development of compact solutions to control axial stress and internal pressure stress
  - ✓ Development of devices to measure on line length and diameter changes

- Technological development of devices & components from 2006 within European Union collaboration (6th Framework program and bilateral collaboration)