PAUL SCHERRER INSTITUT

PSI

Manuel A. Pouchon :: Laboratory Head :: Paul Scherrer Institut

LNM: Labor für Nukleare Materialien

NES Information Event, 18.10.2016

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Mission of LNM

- **CENTRE OF EXCELLENCE:**
  The LNM is the principal research unit and national centre of excellence in Switzerland in the domains of (irradiated) **materials behaviour** and **ageing** in **nuclear installations**.

- **ACADEMIC R&D & SCIENTIFIC SERVICE**
  It provides material-related academic R&D contributions and scientific services to the **sustainability** of **current** and **future nuclear installations** for electricity & heat generation or waste reduction as well as to the performance of **nuclear research facilities**. A special emphasis is placed to the **safety** & **safe long-term operation** of the CH NPPs.

- **Material ageing** in the primary circuit and its impact on **integrity, safety** & **lifetime**
- **Performance** and **safety** of **LWR core materials** in **service** and storage
- **Radiation damage** in structural and core/target materials of advanced nuclear and accelerator systems.
- **Material irradiation program at SINQ** in co-operation with the Spallation Neutron Source Division.
- **Post-irradiation examinations** and **failure analysis** in close cooperation with the Hotlab Division AHL.

Mission of LNM

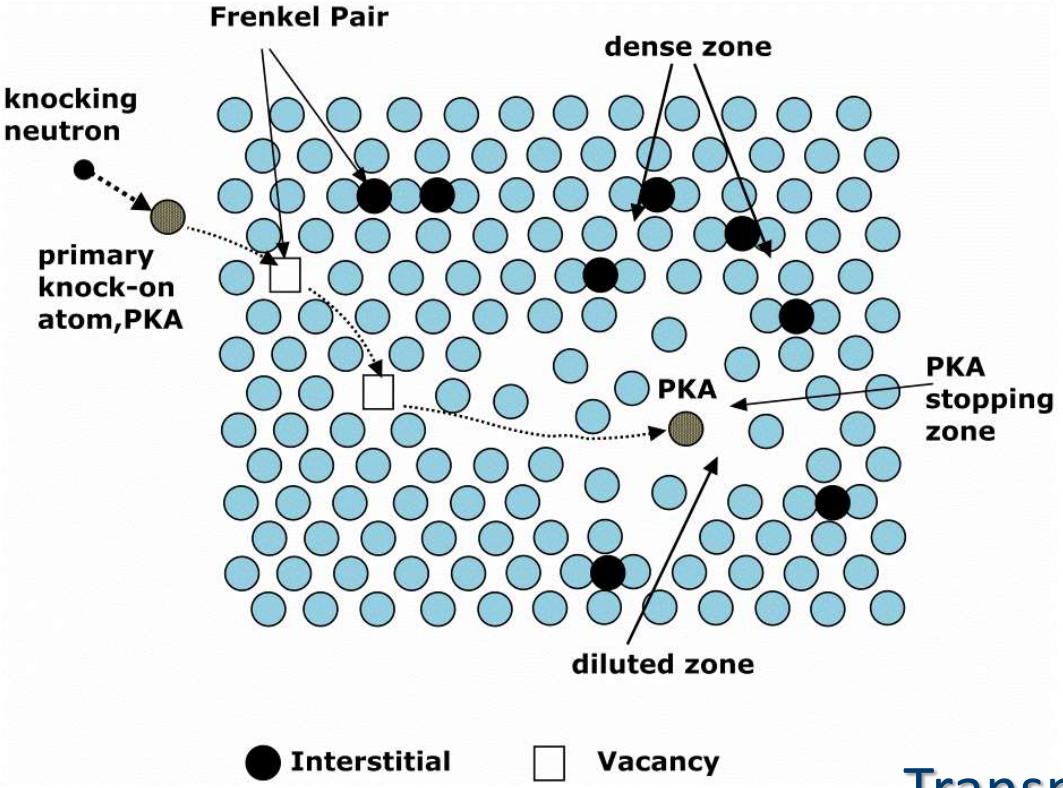
- **KNOWLEDGE MANAGEMENT:**
  LNM is engaged in academic **teaching** and **education** as well as in **knowledge transfer** in its activity fields contributing to the education of the future nuclear specialists and preservation of expertise & excellence.

- **INDEPENDENT EXPETISE:**
  Its **independent expertise** and **excellence** are always available to the **Swiss safety authority**, e.g. for expertise's and consulting (TSO), and for the **industry**, e.g., for material examinations and failure analysis.

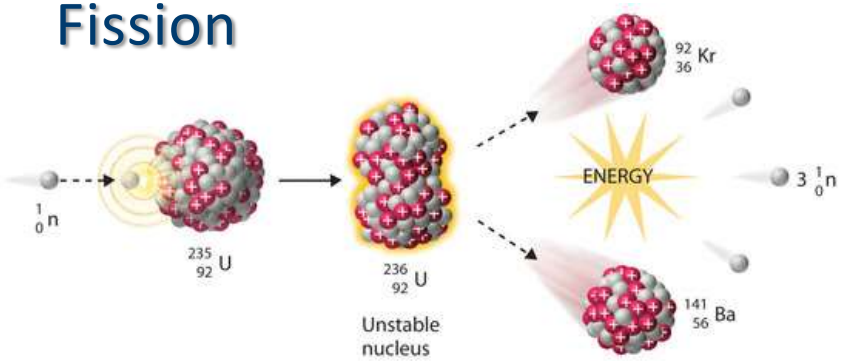
- **STATE OF THE ART INFRASTRUCTURE:**
  It operates a state-of-the-art **lab & computing infrastructure** and **modelling tools** for the **characterization** of **(radioactive) materials** (strongly benefiting from PSI's unique large scale facilities: hotlab, SLS, SINQ, SwissFEL) and for the **analysis & prediction** of the **material behavior, integrity, safety & lifetime.**

Radiation Damage

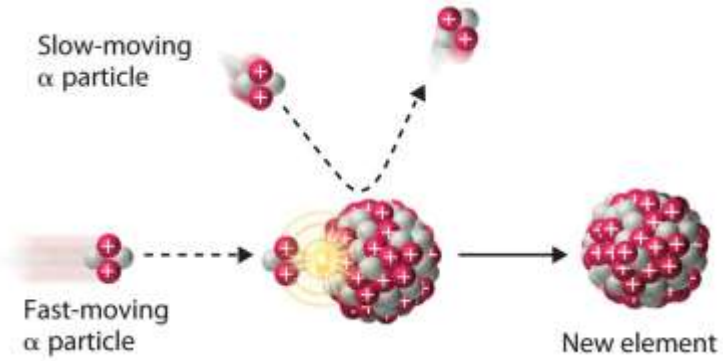
Defects



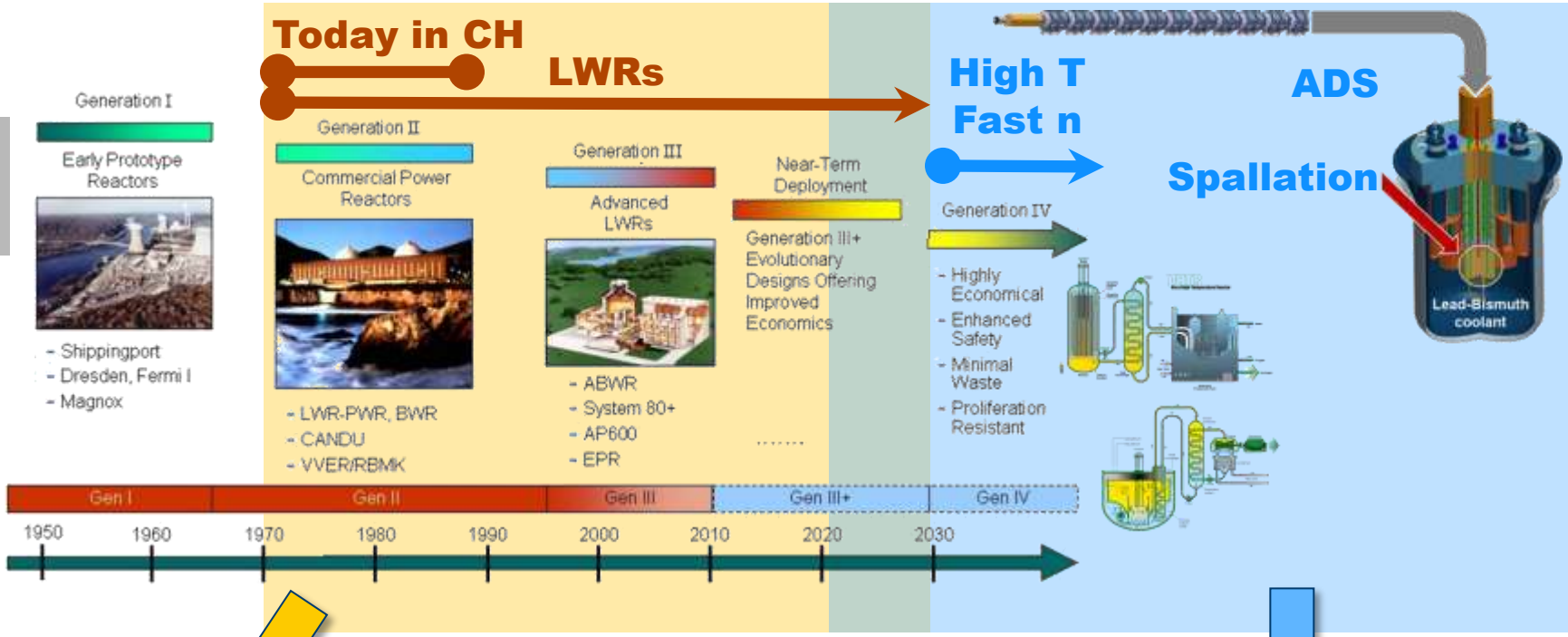
Fission

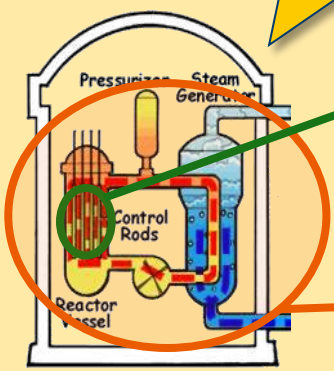


Transmutation



Background - Programs





Nuclear Fuels

Component Structural Integrity

Advanced Nuclear Materials

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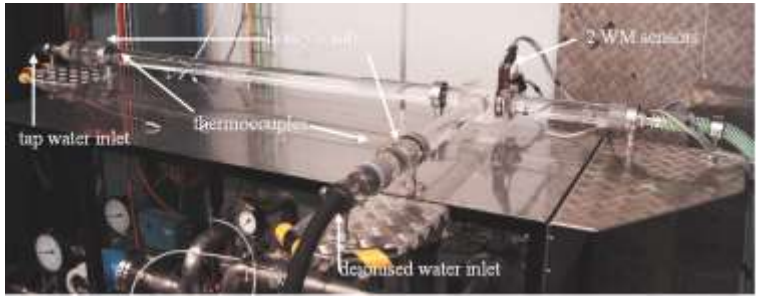
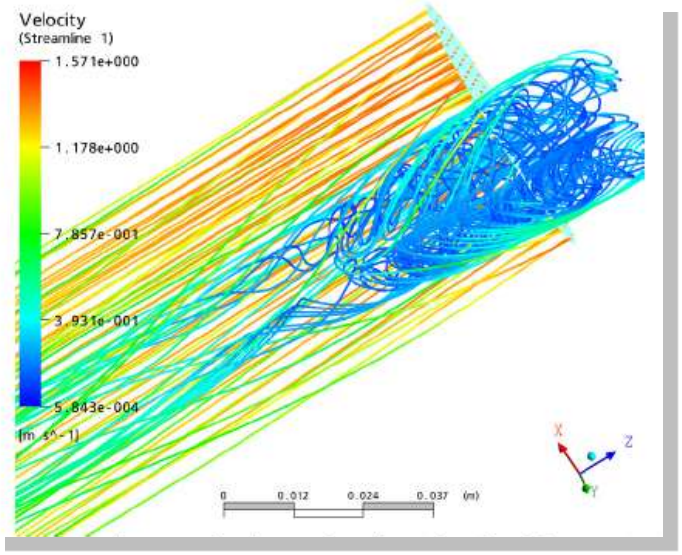
TMF: PLiM-V & VI (swissnculear, 2014-18)

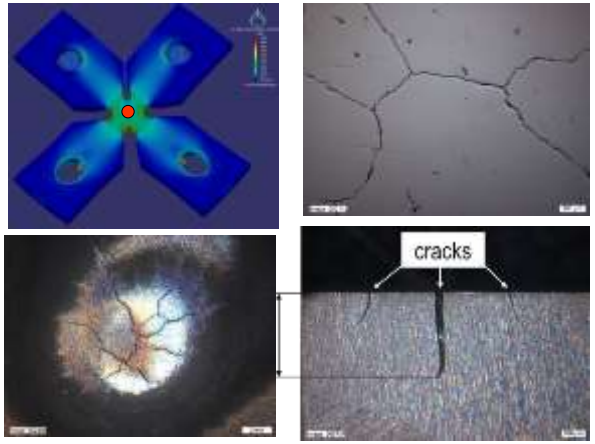
Modeling & Lifetime Prediction of TMF Initiation & Growth under Turbulent Mixing Conditions in T-Joints & Experimental Validation

CFD Modeling & Validation (by LTH)

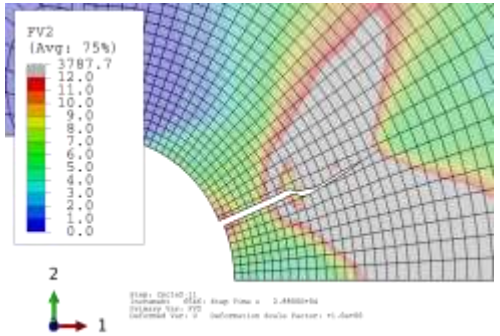




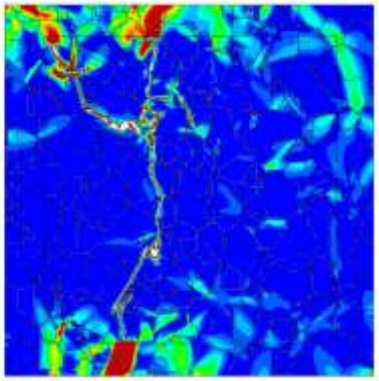
Structural Mechanics Modeling & Validation



continuum-scale

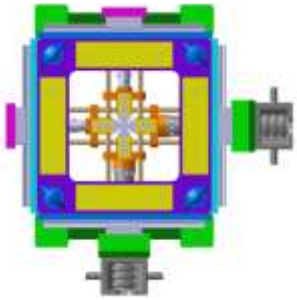


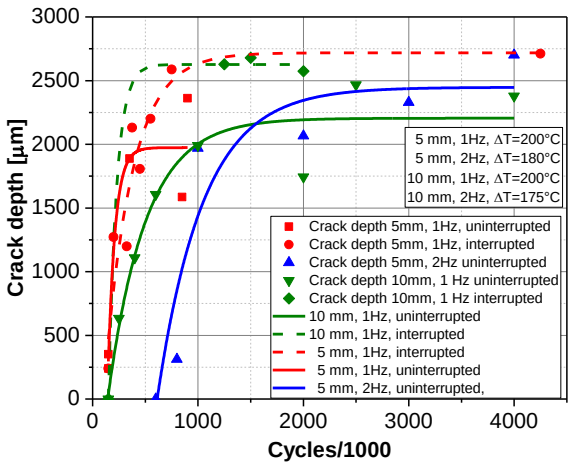
meso-scale



Non-Standard Fatigue Tests for Model Validation & Development

TMF
with biaxial pre-loading

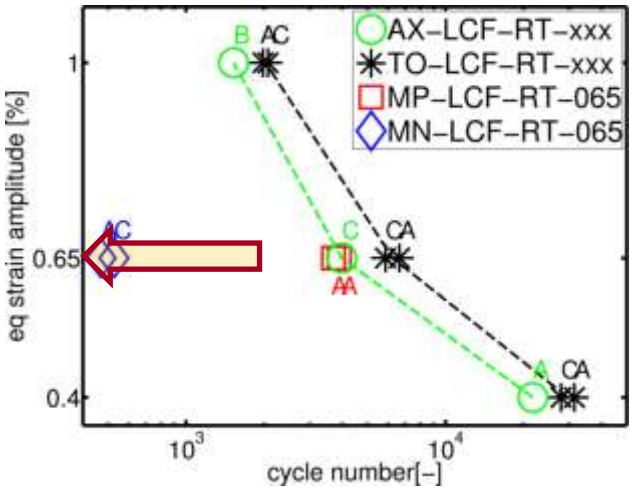




- Crack arrest at 2 to 2.5 mm = f (frequency)
- Strong effect of surface conditions on initiation

HCF
with micro notch (FIB)

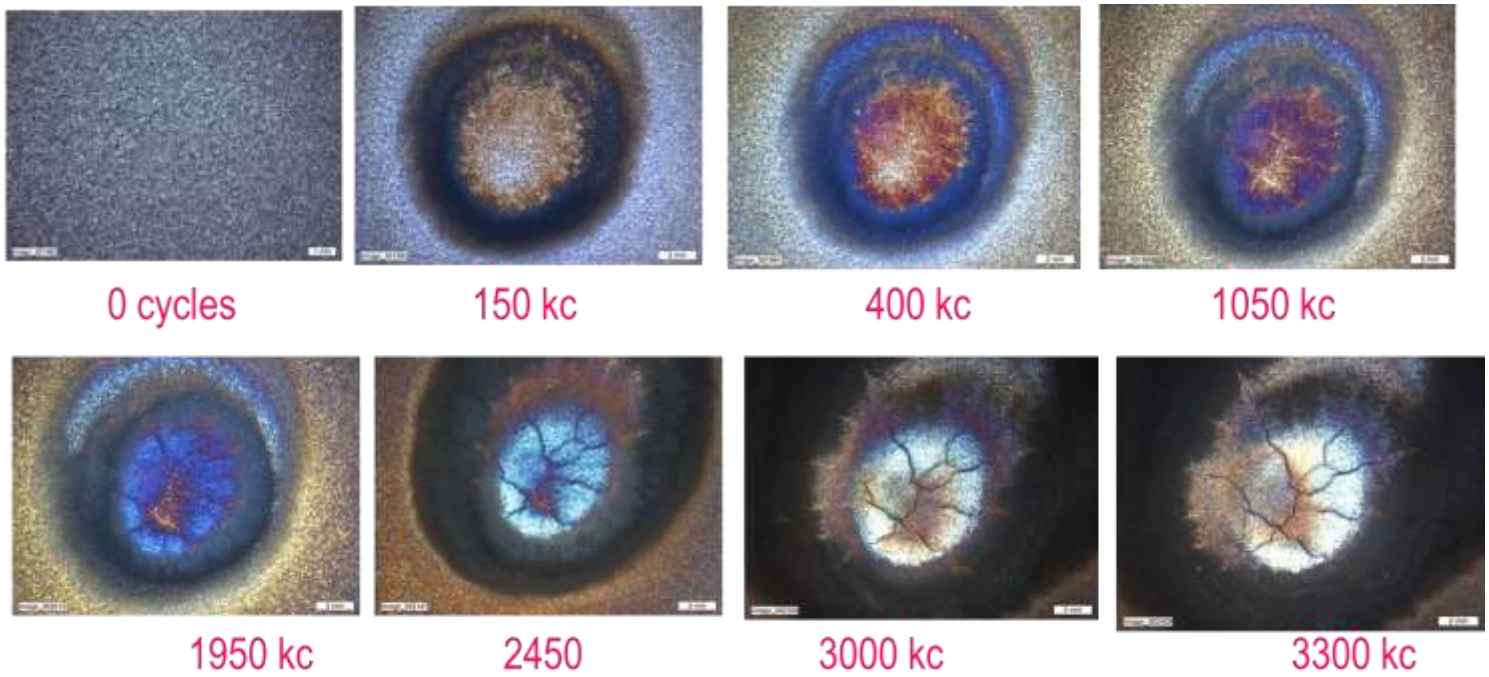
Multiaxial HCF
tension-torsion, proportional & non-proportional



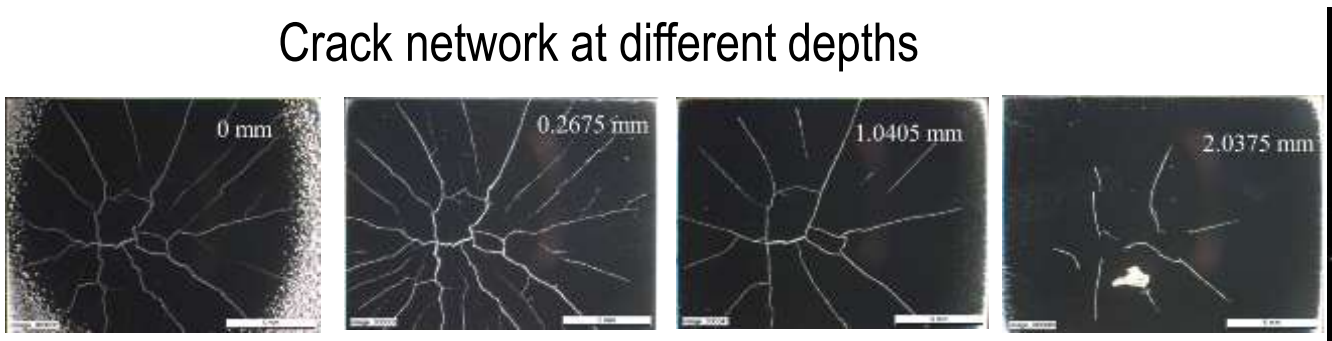
Significantly shorter life in case of multiaxial non-proportional loading!

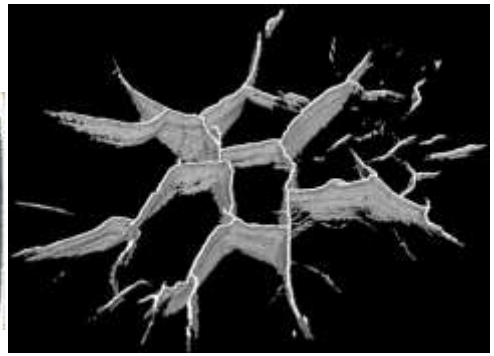
Crack Network Formation due to Cyclic Thermal Shocks

Crack network formation due to cyclic thermal shocks (ΔT=160 °C, 1Hz, H_2O)

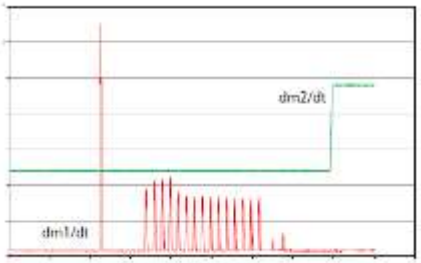


Crack network at different depths



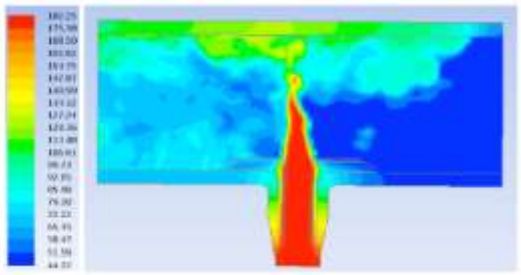


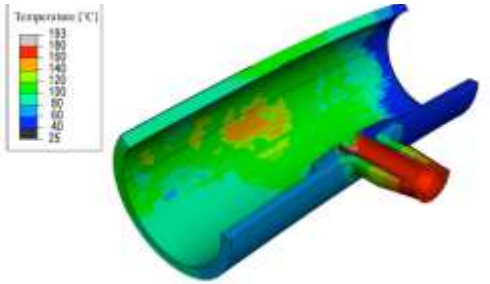
Lifetime Assessment of Mixing T-Joint in KKM

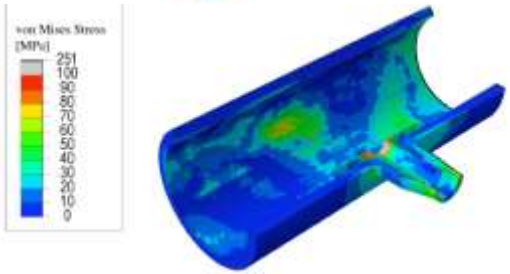


Load Case 1

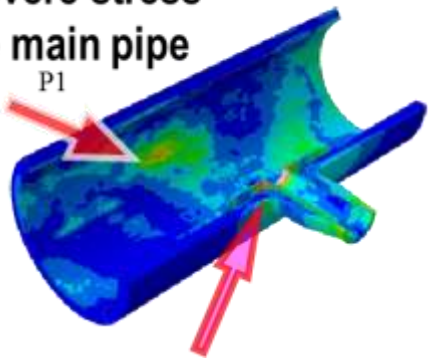
	Flow Rate [t/h]	Inlet Temperature [°C]	Coolant Pressure [bar]	Reynolds No.
Main	32	48	25	7.4×10^4
Branch	12	180	25	4.1×10^5



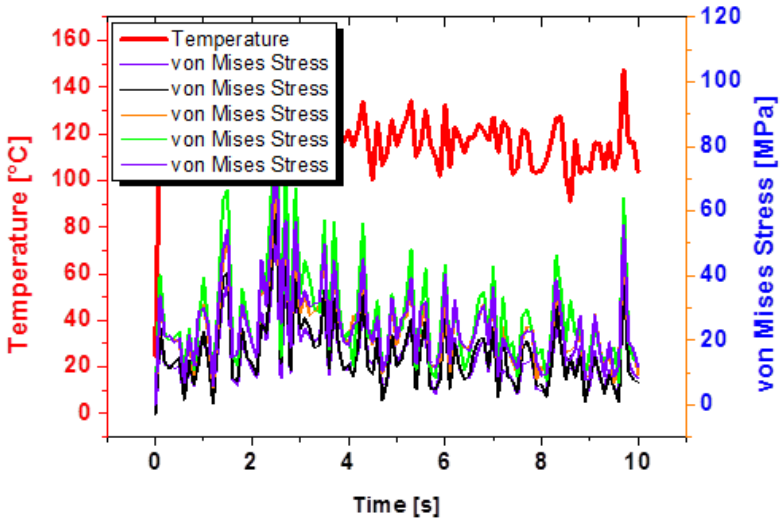




Areas of most severe stress transients in the main pipe



Stress & temperature at P1 vs time



- Surface crazing not excluded for certain load cases
- Challenging evaluation of complex combined high & low frequency, multi-axial, variable amplitude fatigue load

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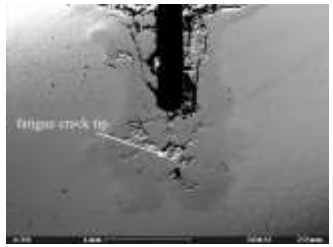
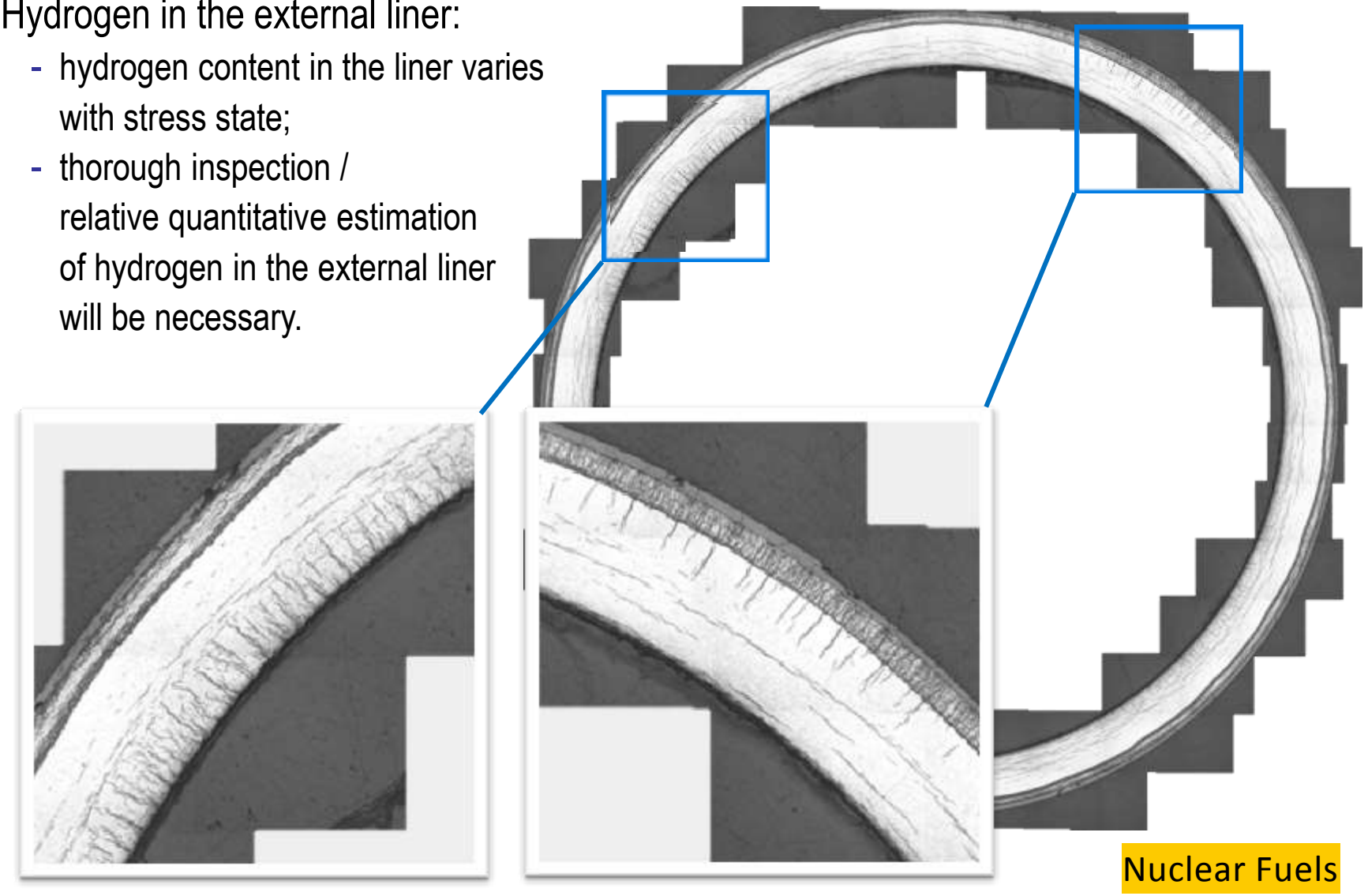
Hydrides in Cladding (Zircaloy)



Hydrogen in the external liner:

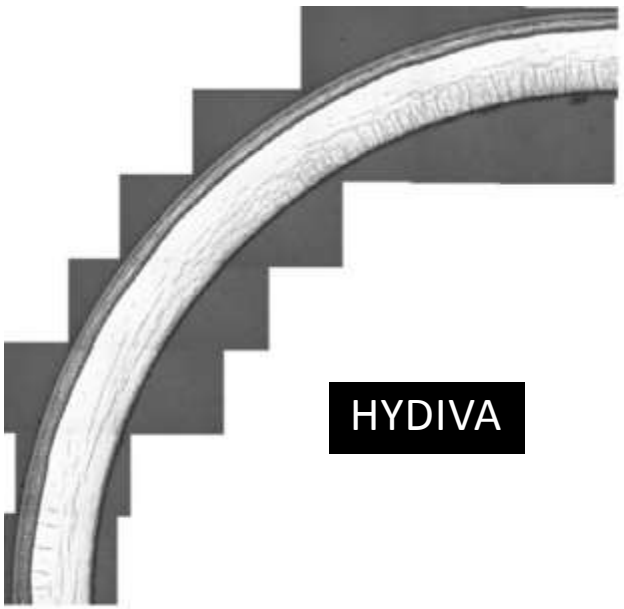
- hydrogen content in the liner varies with stress state;
- thorough inspection / relative quantitative estimation of hydrogen in the external liner will be necessary.



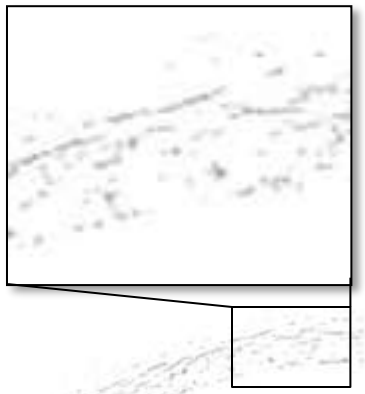
Nuclear Fuels

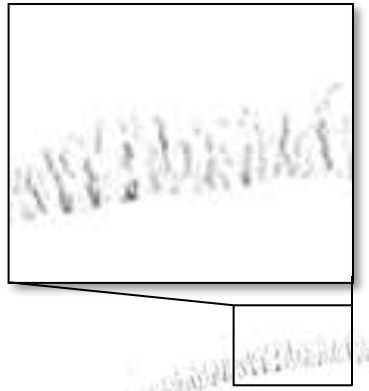
Hydrides re-orientation KKG

Zry-4 duplex DX-D4,
AREVA, KKG
BU 72 GW d t^{-1}

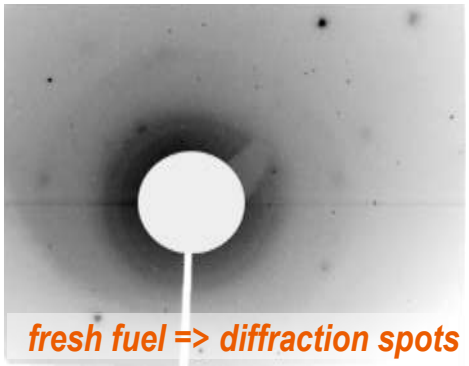


HYDIVA

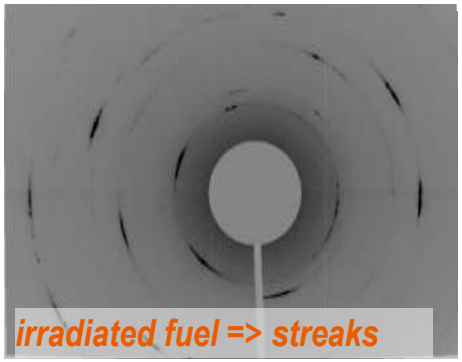




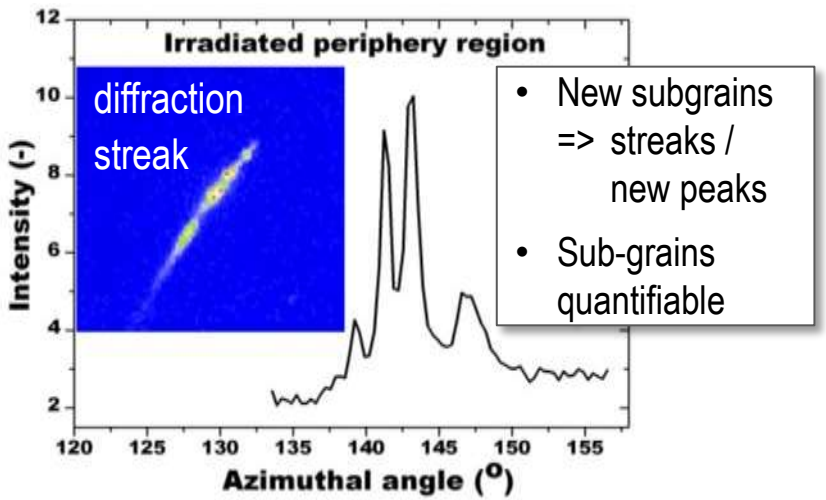
Nuclear Fuel: XRD & EXAFS



fresh fuel => diffraction spots

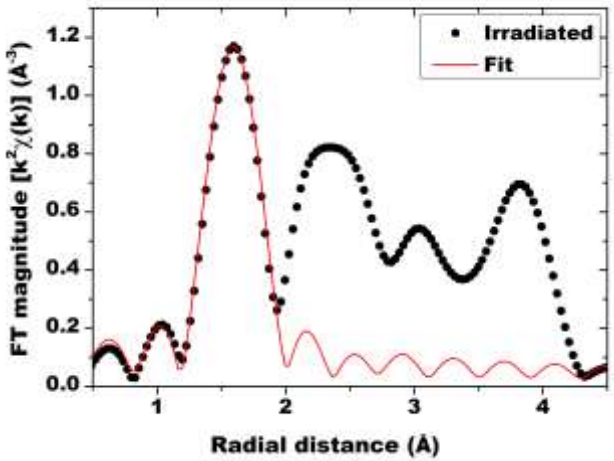


irradiated fuel => streaks

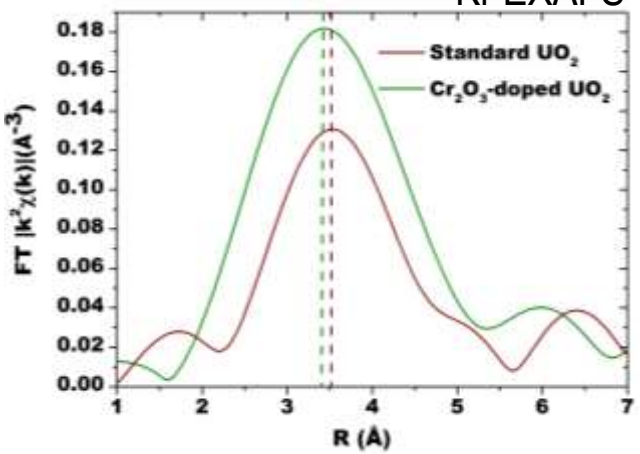


- New subgrains => streaks / new peaks
- Sub-grains quantifiable

Cr EXAFS



Kr EXAFS



Work performed in multilateral collaboration

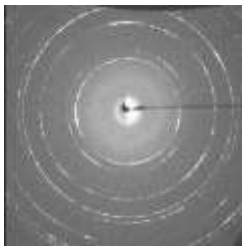
→ Hotlab (AHL) → Industry (Areva)

→ LNM → Université Paris-Sud

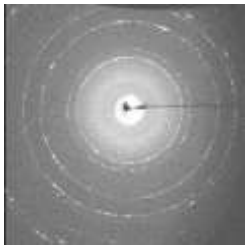
Nuclear Fuels

High burn-up fuel & restructuring

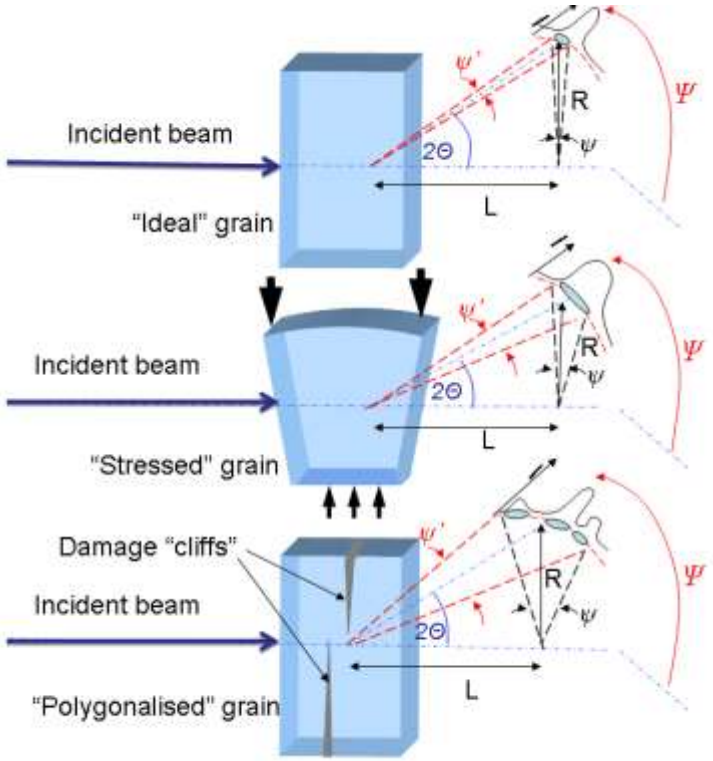
Fresh UO_2
Grain > beam size
of 1 x 2 µm^2



Pellet center
(9 cycles)



Periphery
(9 cycles)



At 9 cycles:

- quasi-full Debye rings (powder-like)
- very fine grains (< 1-2 µm) <u>in whole sample</u>

On-going analyses 5 and 7 cycles:

- polygonisation has started
- stresses?

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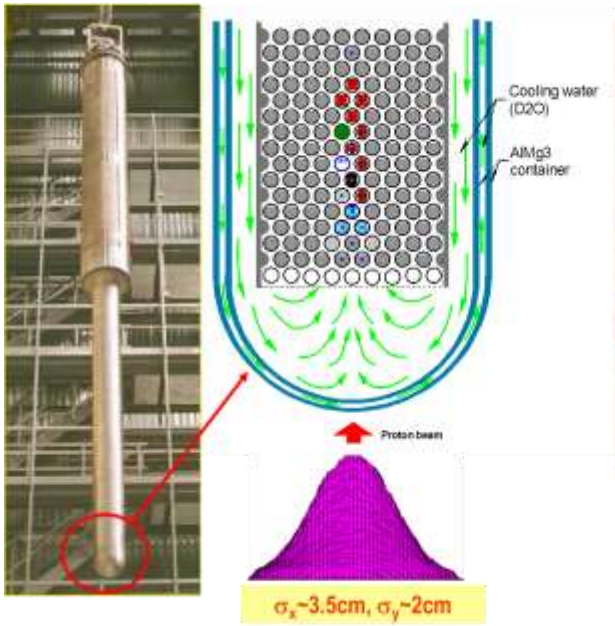
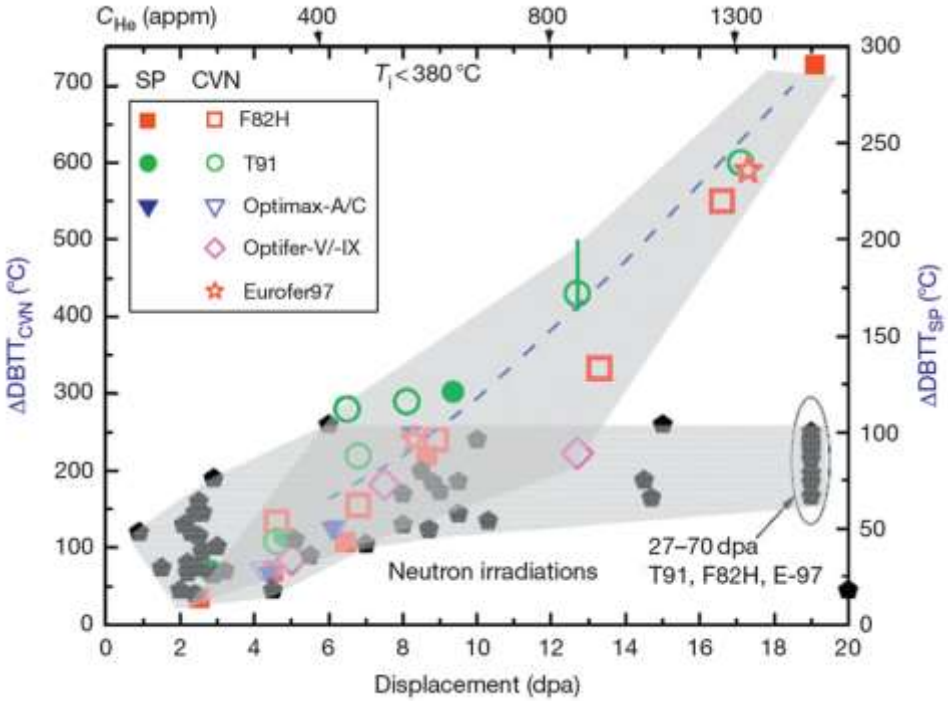
STIP program – Materials in Spallation Target

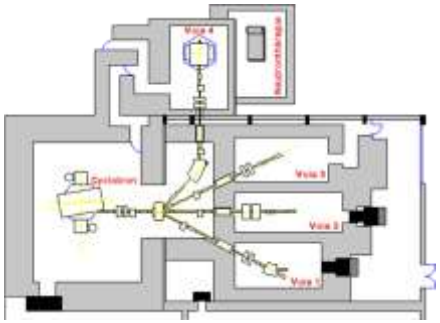


Embrittlement of FM Steels

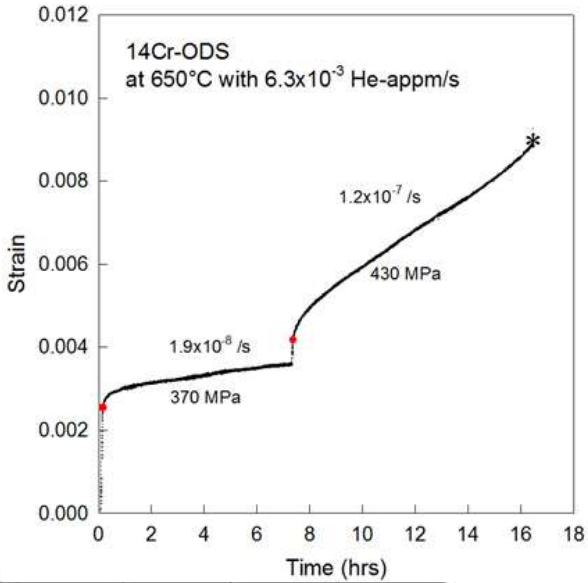
(high He production)

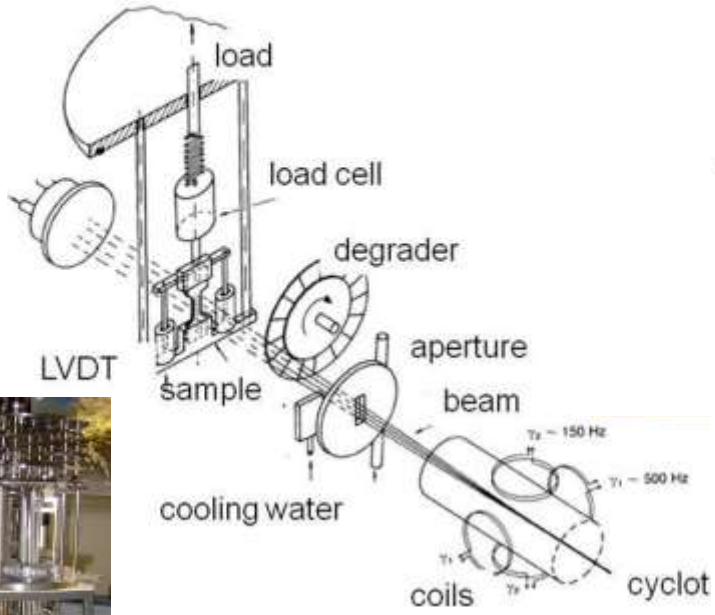


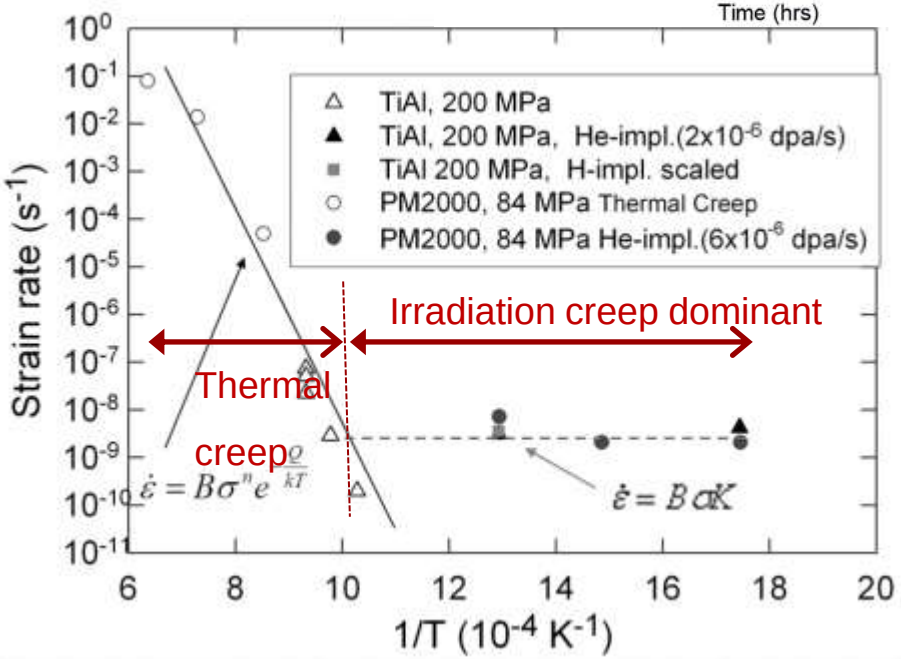
In-Situ Irradiation Creep



Ions	Energy (MeV)	Intensity (μA)	Range (μm)
p	5--38	15	2800
H_2^+	5--25	13	380
d	5--25	40	760
α	10--50	15	380
^3He	10--50	15	470



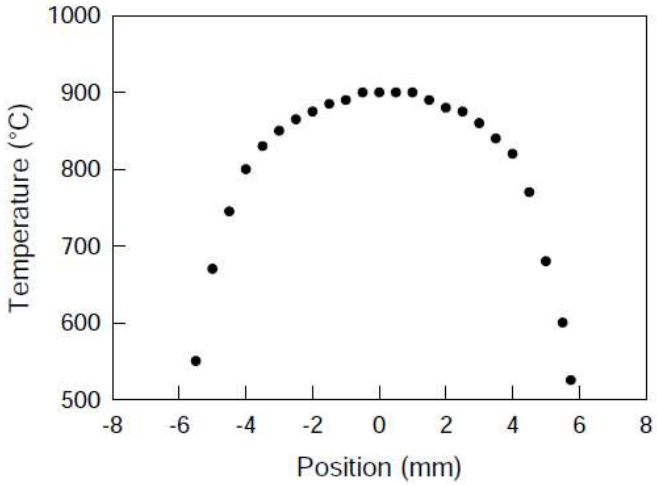




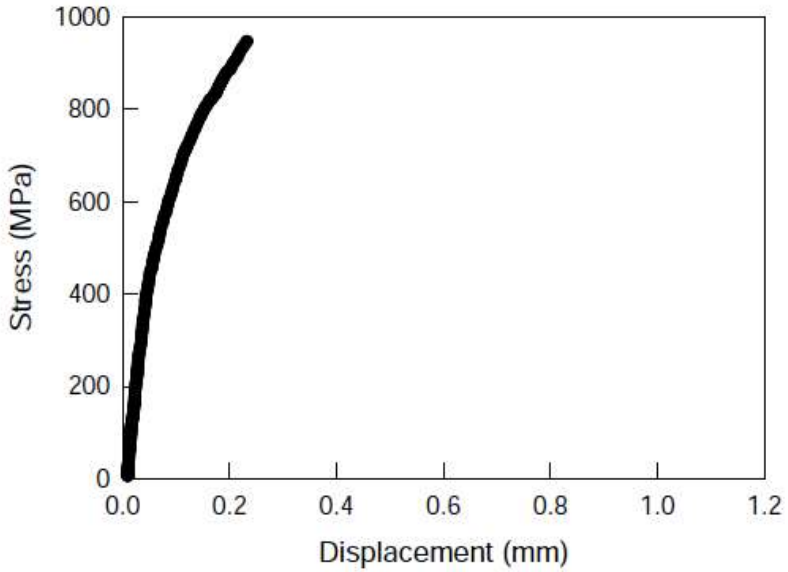
Progress on Irradiation creep of SiC_f composites

supported by French national program "Needs"

Temperature profile along the SiCf sample No.2



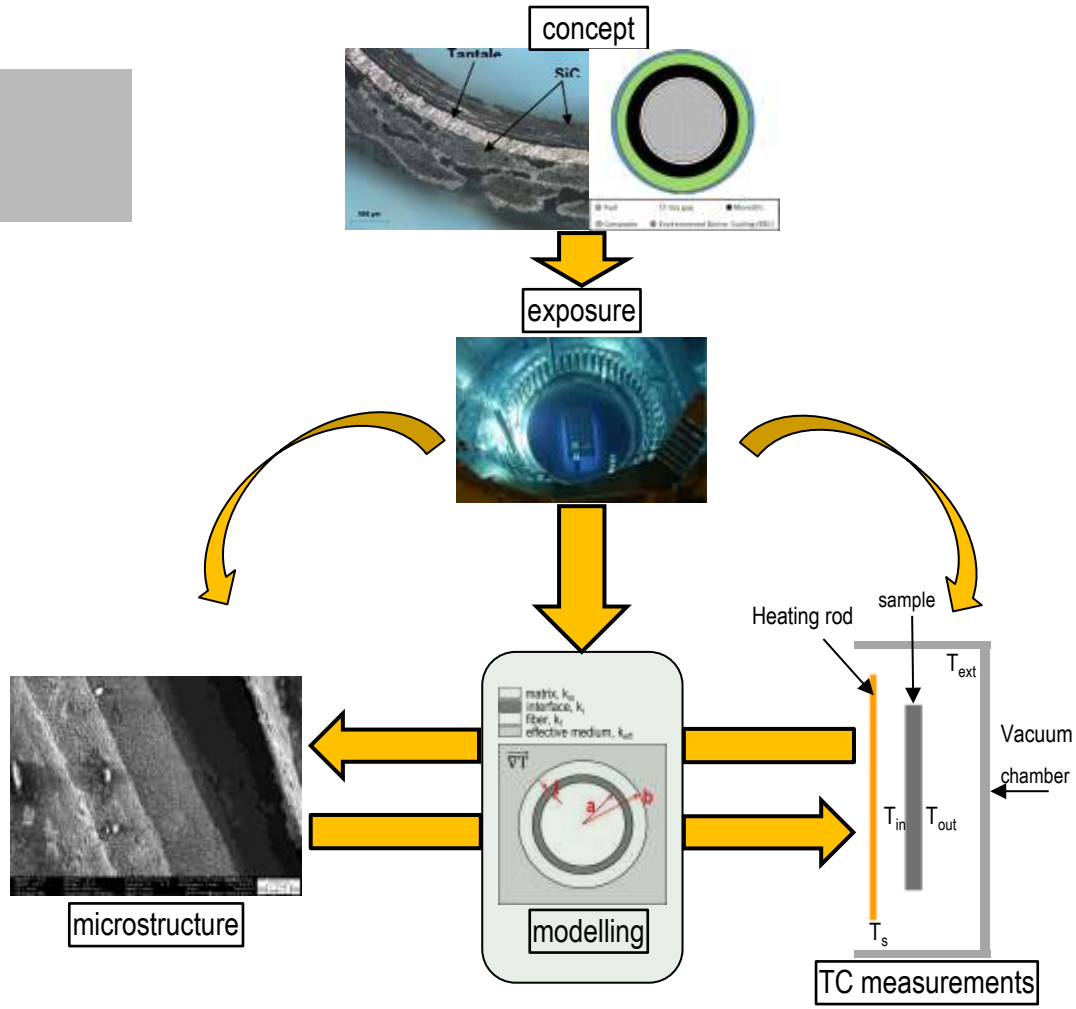
SiCf No. 2
Tensile test at 900°C with beam



Aperture size: 12X4.5 mm^2
Beam current 5.6 µA

Uniaxial loading system for mini SiCf (0.5 mm in diameter) composites sample is successfully developed.

Accident Tolerant Cladding - Conductivity



Three blocks

- **TC measurements**
  on actual cladding tubes
  - ➢ Carried out on samples obtained through MatISSE and industry partners
- **Microstructure** study with EM
  - ➢ TEM → structure
  - ➢ EFTEM → effect of irradiation
  - ➢ FIB → samples and tomography
- **Modelling**
  link observations to measurements in a continuous medium based model

→ Effect/behavior of PyC interphase before/after irradiation

Loïc Fave - EPFL Thesis № 7378 (2016)

Wir schaffen Wissen – heute für morgen

Nuclear Materials Research at PSI is active…

… serving the authorities and industry with safety investigations.

… helping the industry with performance optimizations.

… contributing to education and training.

… contributing to the next generation research.

My thanks go to

- All the members of LNM for their great efforts & performance
- AHL / SU / NES / NUM
- All external partners like ENSI, swissnuclear, CCEM, SNF, …

LNM & Friends