CERMET PuO_2 - Ferritic Stainless Steel Fuel Development and Performance Evaluation with COMETHE Code

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Objectives of a PuO_2- Ferritic Stainless Steel CERMET

- Enhanced plutonium and TRU-burning in existing power reactors
- Enhanced reduction of spent fuel volume, heat generation and long term radio-toxicity
- Power produced using plutonium and TRU generates revenue and helps reducing their total disposal costs
- Compatibility with design and safety criteria of existing oxide fuels
- Compatibility with fabrication in existing plutonium processing plants

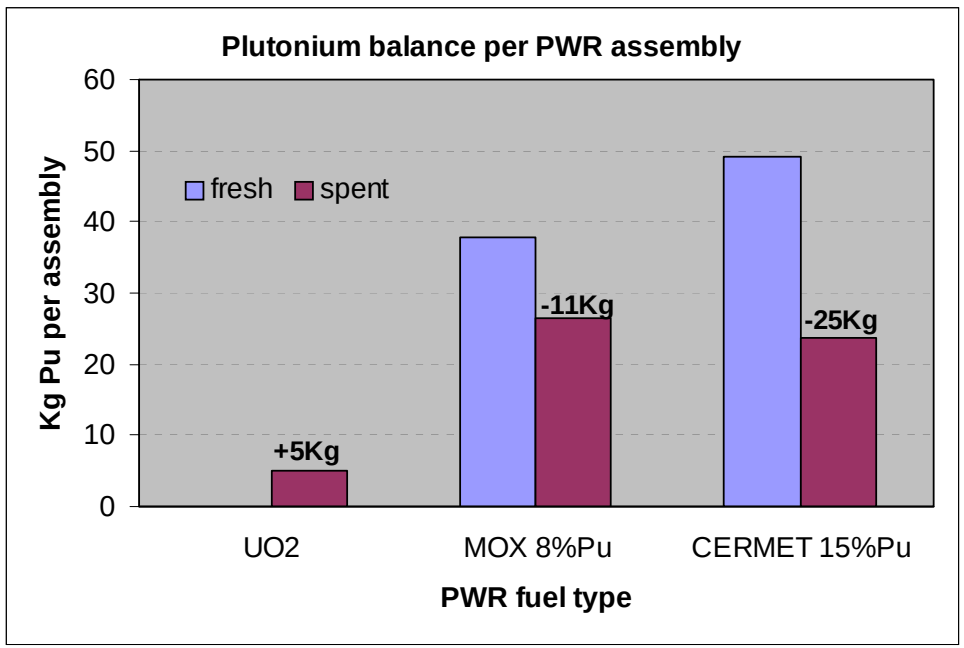
Design approach

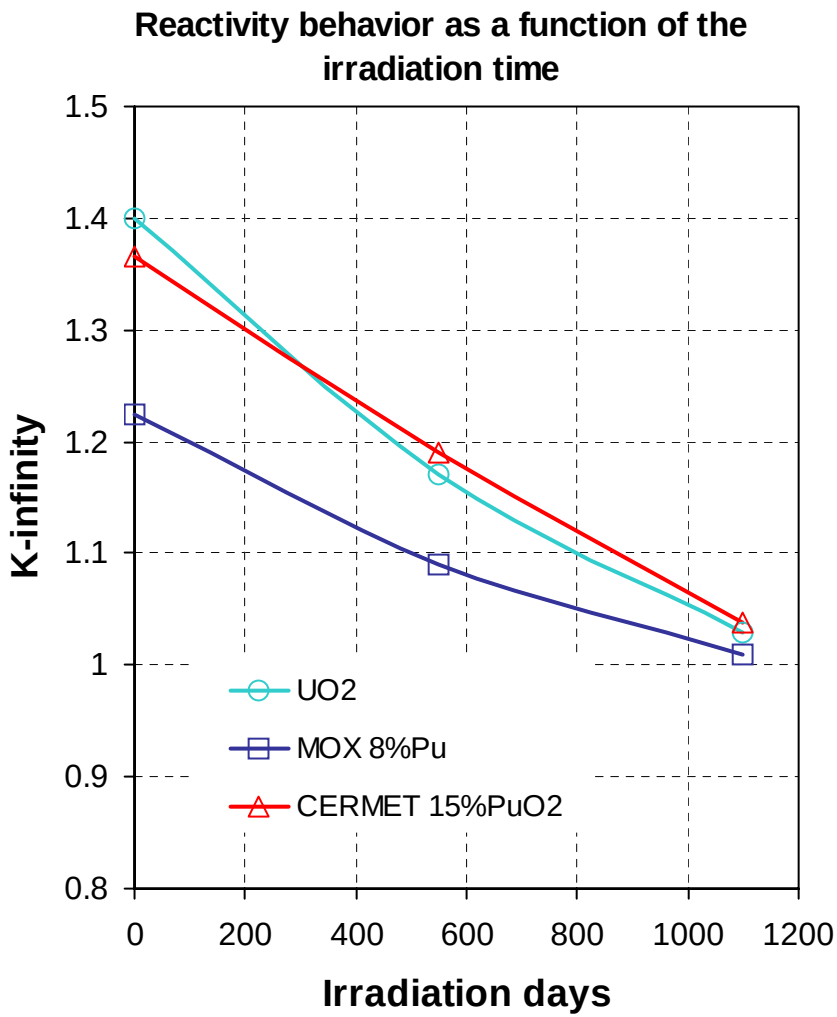
- Conservative approach by using existing design of pellets/rods/ assemblies
- Neutronic evaluation studies
- Surrogate fabrication test
- In-reactor thermo-mechanical behavior

“ TRUCE is a pre-qualification program prior to industrial demonstration in commercial reactors “

Neutronic Aspects

- FA reactivity (see figure)
- FA power sharing: better than MOX
- Moderator Thermal Coefficient: -16.5 pcm/K
- FTC - Doppler Coefficient: -1 pcm/K
- Void coefficient: -2900 pcm/K for a density of 0.4
- Achieved Burnup of 50% FIMA
- EOL/BOL actinides balance: -52%

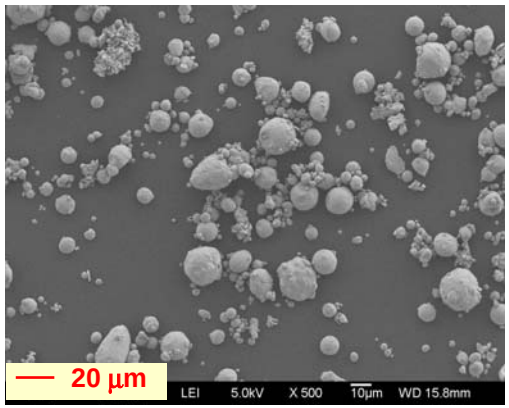




Fabrication test: Powders

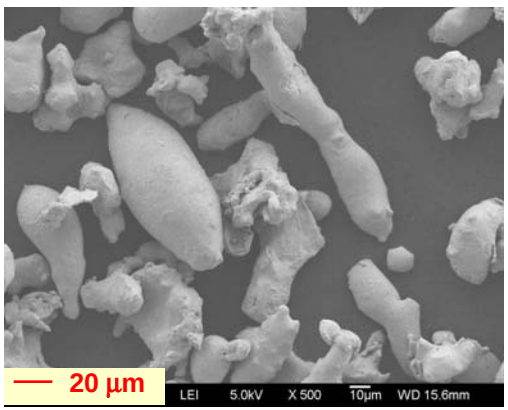
Ferritic Stainless steel powders

- **Gas-atomized**



D≈12µm

- **Water-atomized**



D≈60µm

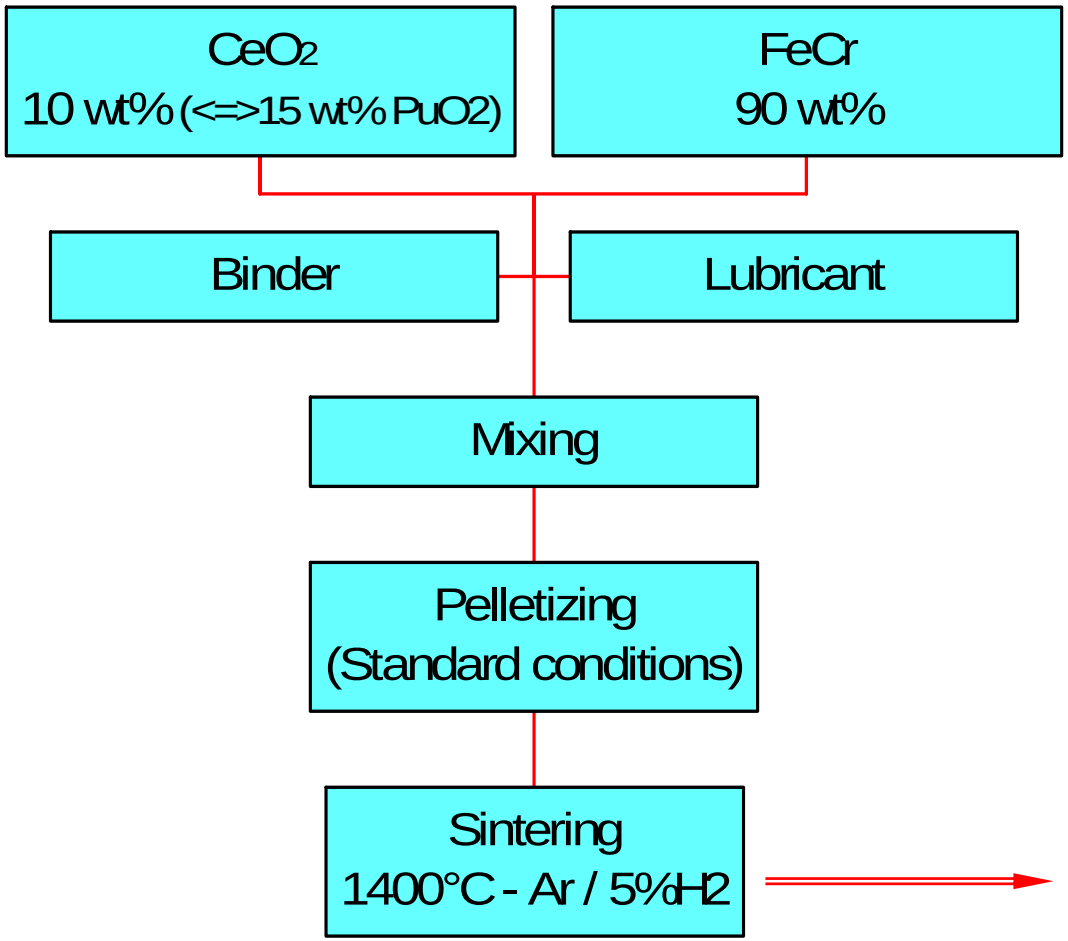
CeO_2 powders (surrogate for PuO_2)

- **Micronized CeO_2 powder**

- **Granulated CeO_2 powder**

71-125 µm

Fabrication test: Pellets

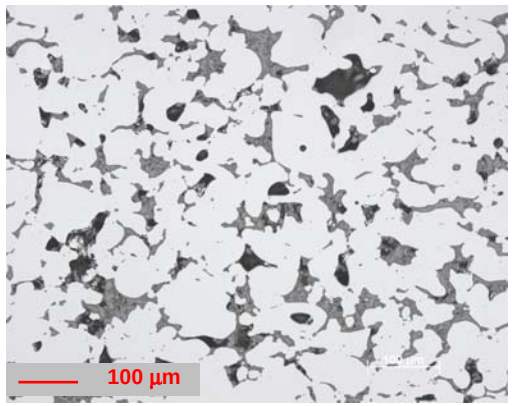


- 90-95%TD
- high stability
- no grinding

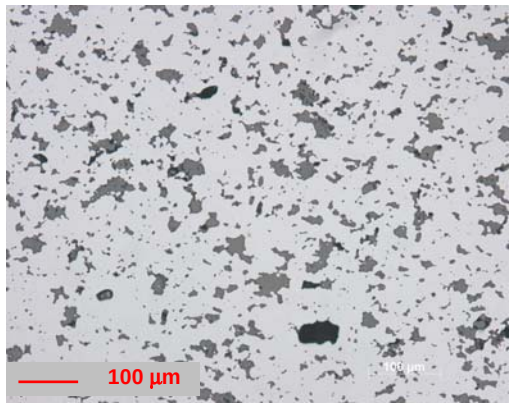
Fabrication test: Microstructure

dispersed CERMET

granulated CERMET

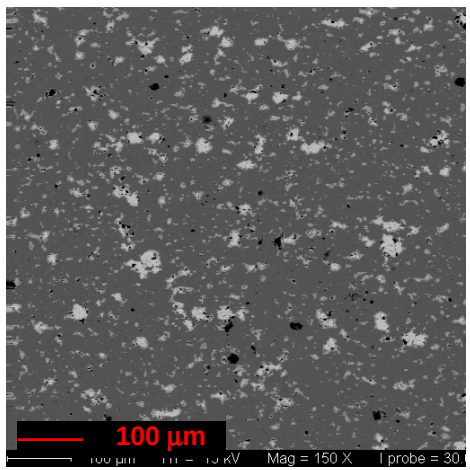


Water-atomized stainless steel

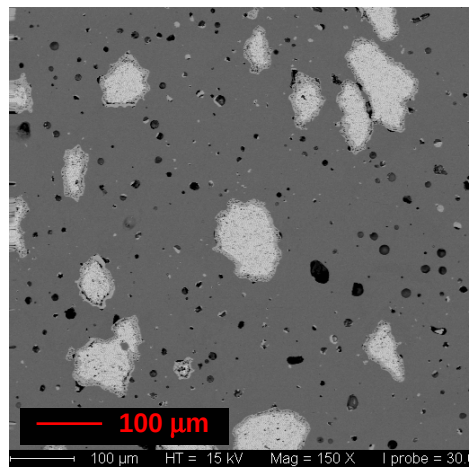


Gas-atomized stainless steel

Gas-atomized stainless steel

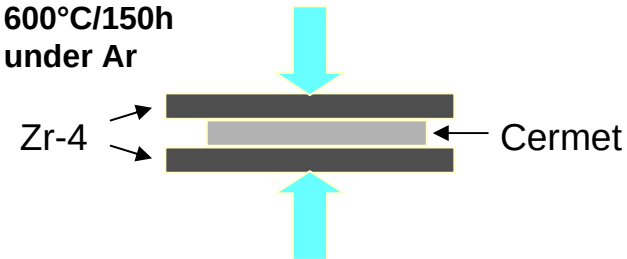


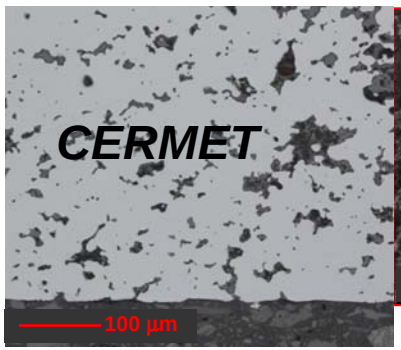
EPMA

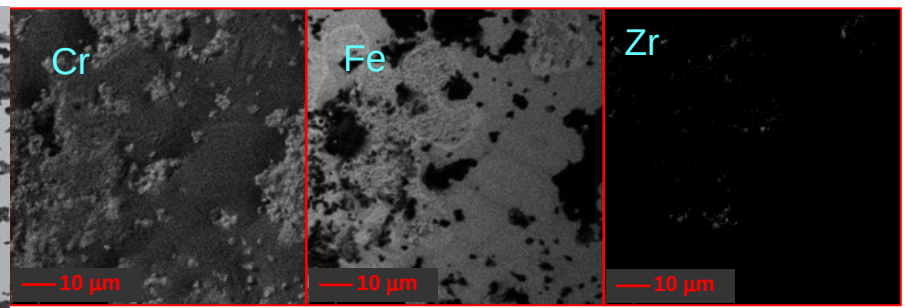


Pellet-Cladding compatibility

600°C/150h under Ar

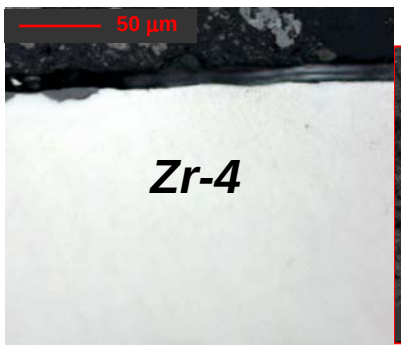


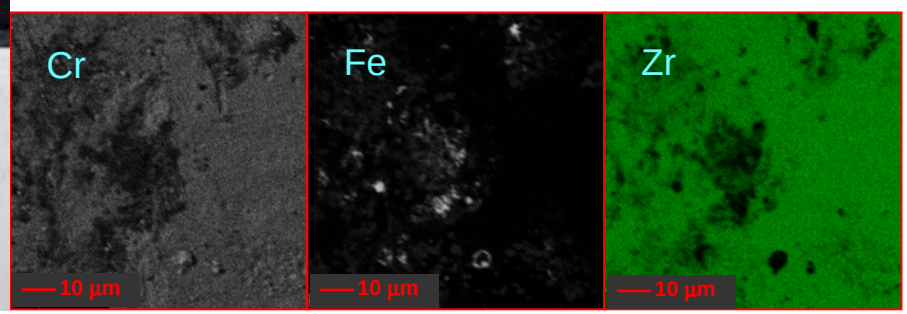


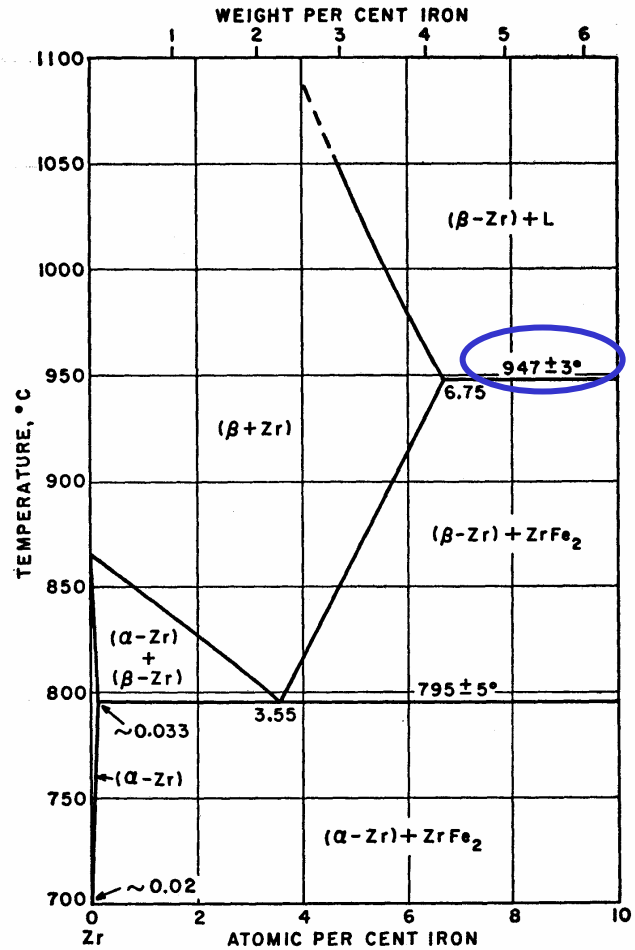


interface

EPMA on contact surface







Tanner & Levinson, *Trans. AIME*, **215** (1959)

Fabrication test: Conclusions

The CeO_2/FeCr surrogate fabrication tests permitted to:

- selection of a ferritic SS powder (flowability, sinterability)
- assessment of the suitability of a standard fabrication process

⇒ high chemical, mechanical and geometrical stability of the CERMET pellet

⇒ dense CERMET (low open porosity)

⇒ homogenous distribution of the oxide phase

⇒ no interaction between the matrix and the cladding

⇒ no need for grinding

⇒ ***suitability for PuO_2-Ferritic Stainless Steel CERMET***

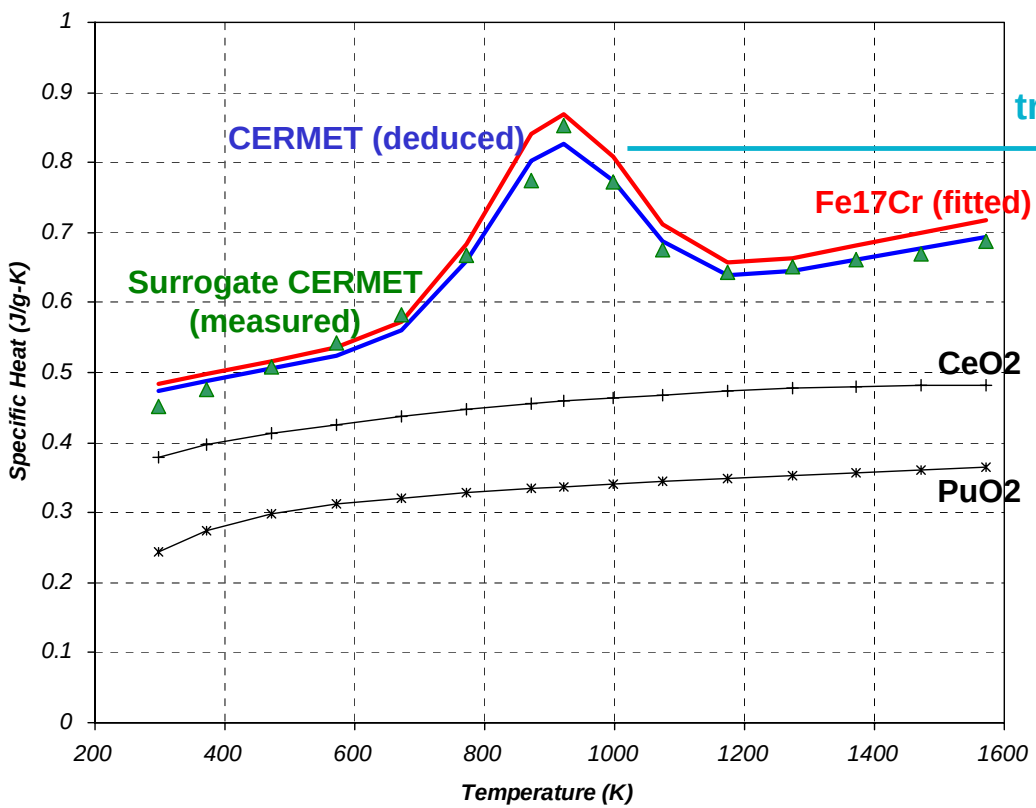
Physical Properties

Physical properties of PuO_2-Cermet needed to be assessed / measured from surrogate Cermet, PuO_2 and Fe17Cr

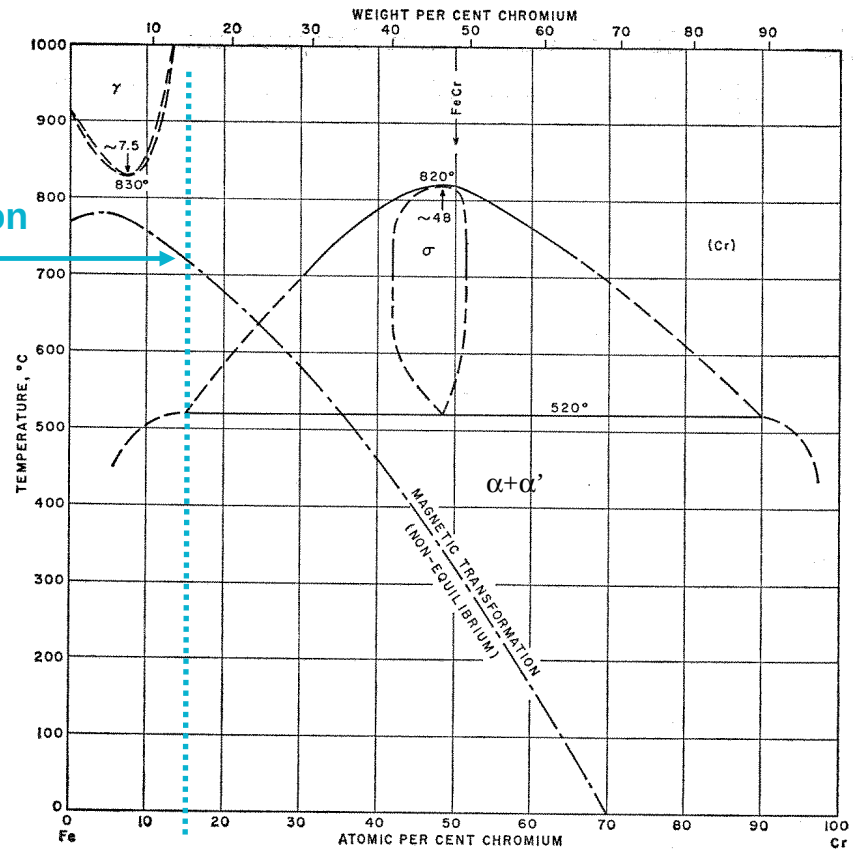
- Density
- Thermal expansion
- Elastic modulus and Poisson ratio
- Emissivity
- Specific heat
- Thermal conductivity

Physical Properties

Cp measured and deduced using Neumann-Kopp rule



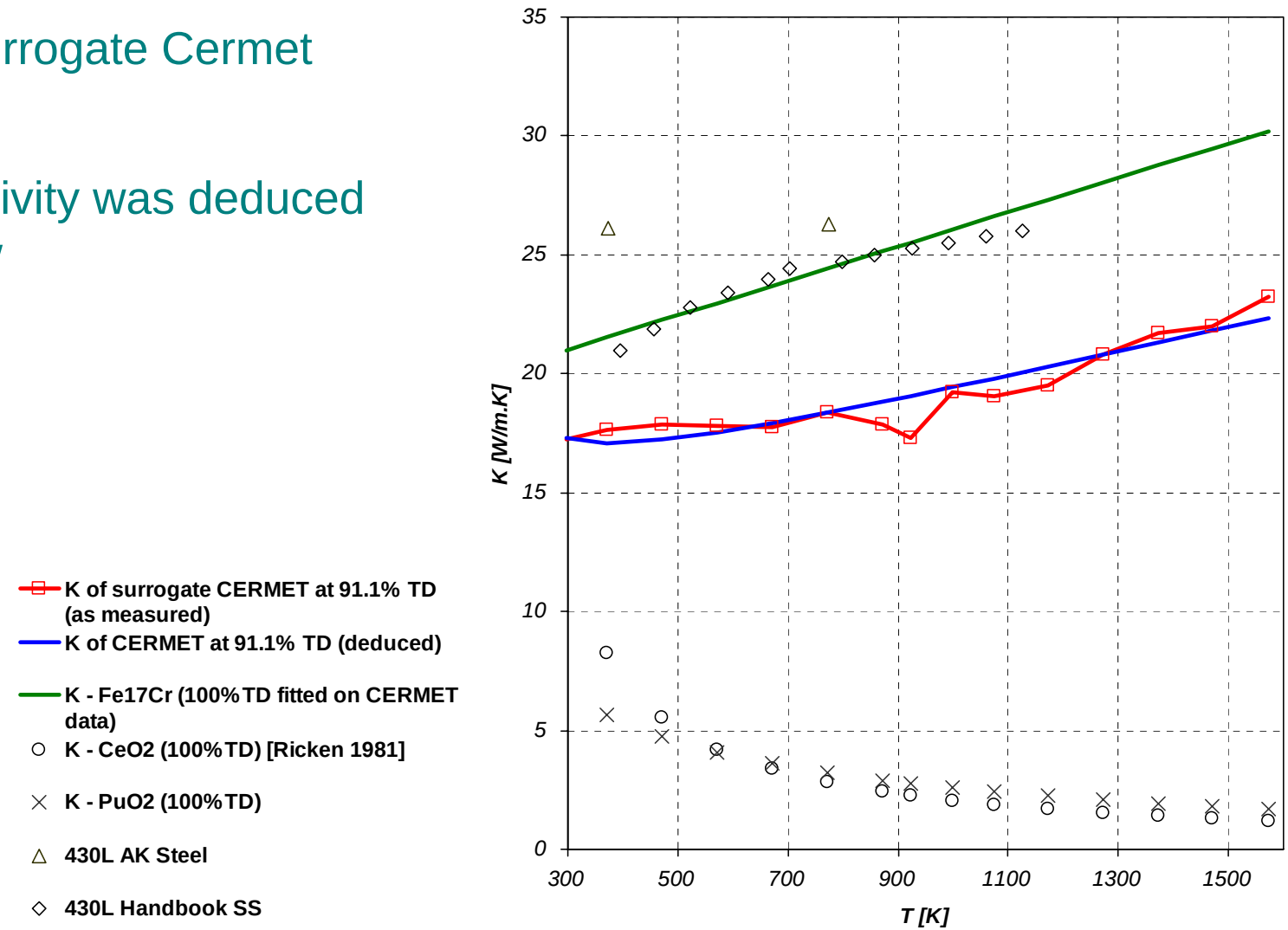
Curie transition



after D. Peckner & al. (1977).

Thermal Conductivity

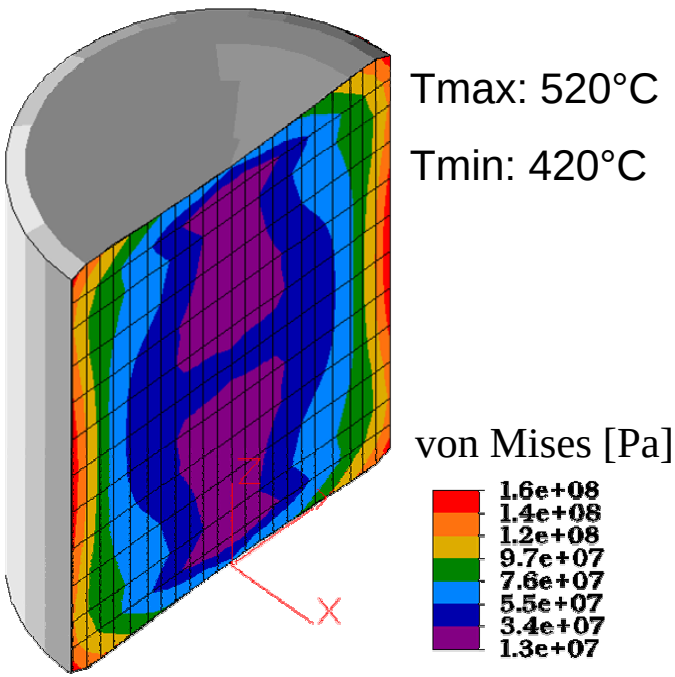
- Measured on surrogate Cermet by laser flash
- Fe17Cr conductivity was deduced using Fricke law



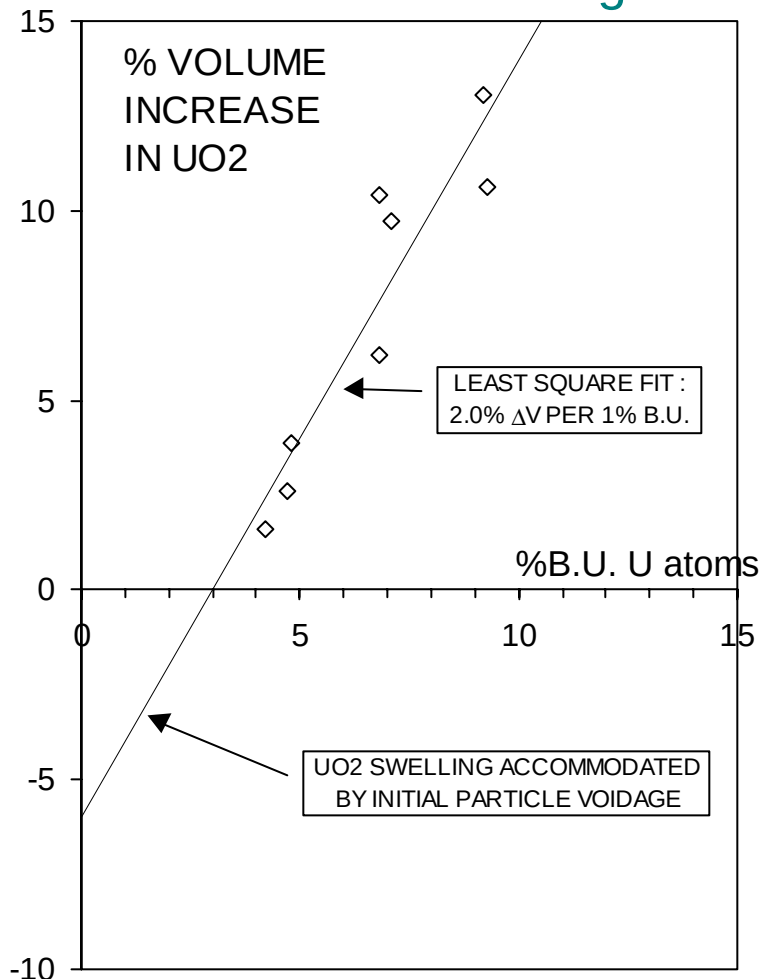
Thermo-mechanical Properties

Mechanical behavior:

- Well below the tensile yield stress
- no fragmentation of the pellet



Irradiation swelling



After J.D.B. Lambert (1966)

Thermo-mechanical Evaluation

Calculations by COMETHE-4D

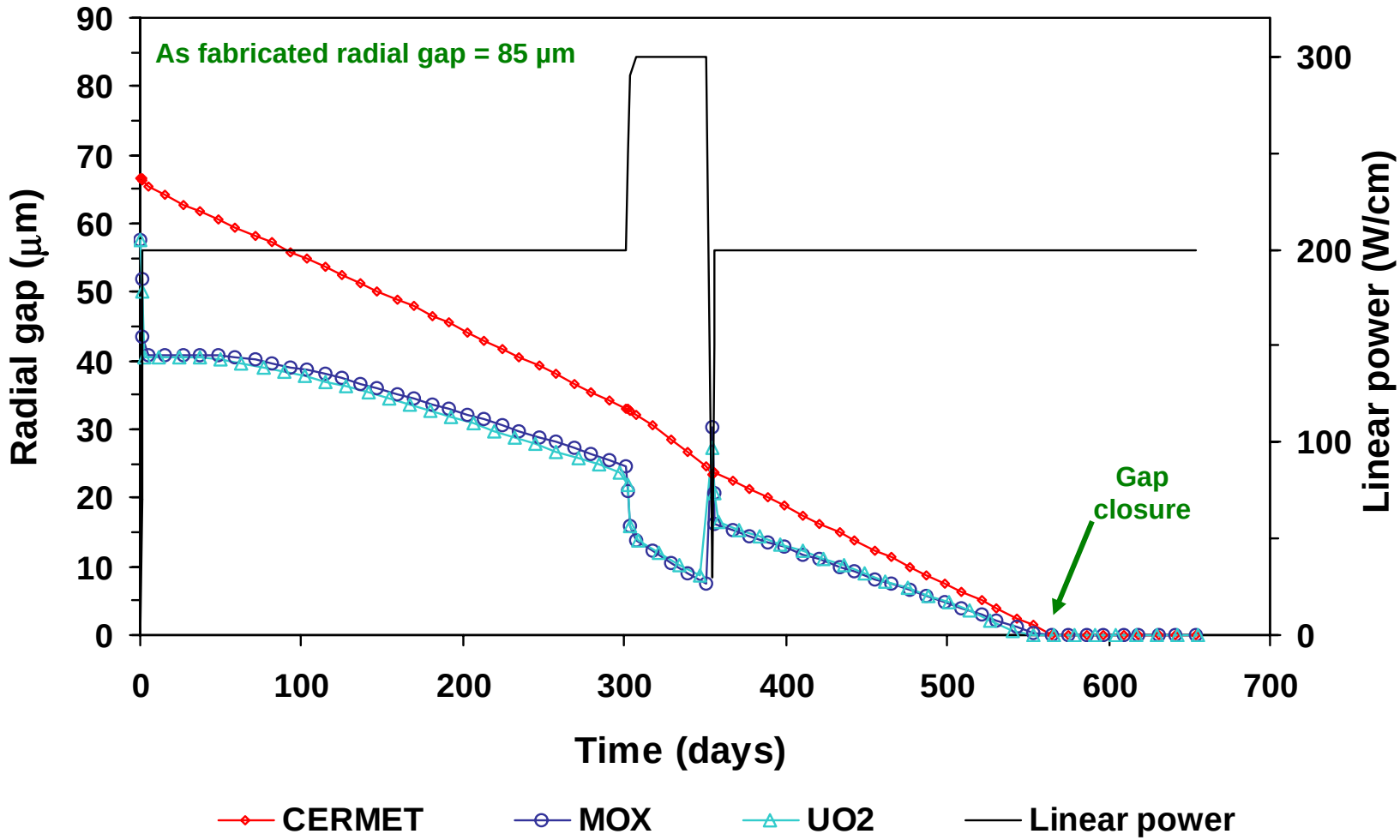
- CERMET (15%Pu)
- MOX (8%Pu)
- UO2

Irradiation conditions:

- PWR 17x17 design
- similar pellet geometry and cladding characteristics
- basis irradiation (200W/cm) and ramp test (300W/cm)

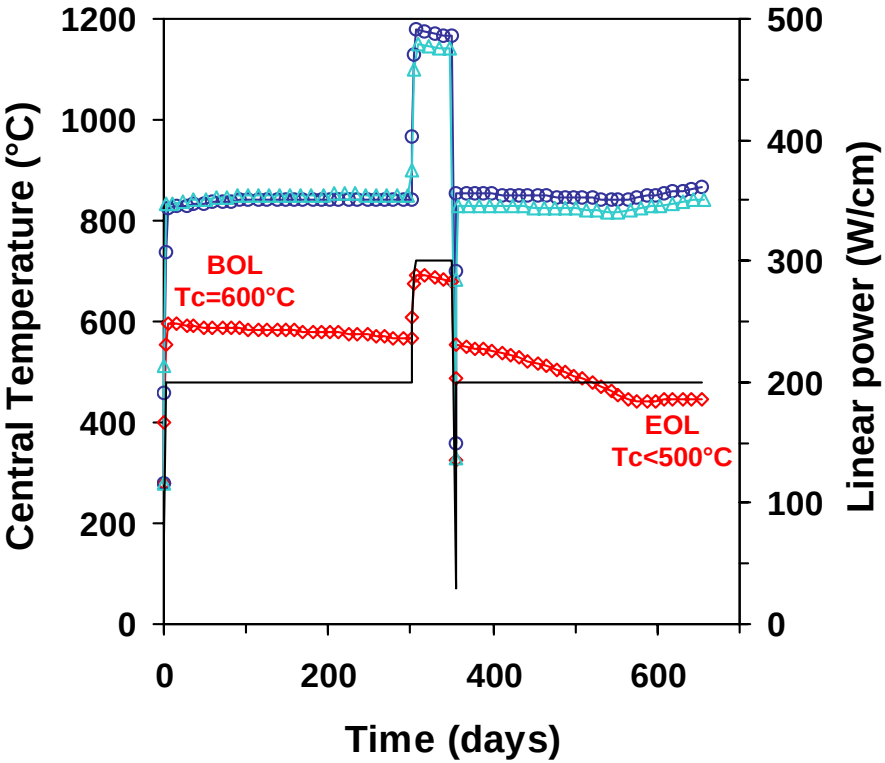
Thermo-mechanical Evaluation

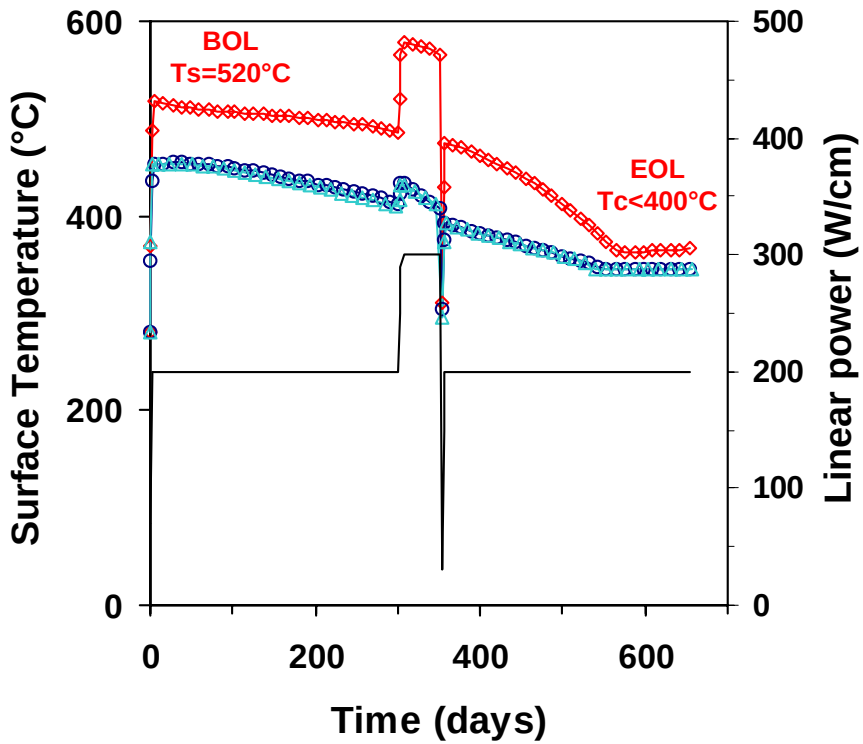
Pellet-clad gap



Thermo-mechanical Evaluation

Fuel rod temperature





CERMET MOX UO2

Thermo-mechanical Evaluation

Achieved Burnup : CERMET ~250 GWd/tox

MOX-UO_2 ~25 GWd/tox

FGR not evaluated (mechanisms of FG diffusion in ferritic matrix unknown)

- generation of FP in porous fissile particles
- dense and stable matrix
- low fuel temperature

=> *low FGR is expected*

Conclusions

- Low central temperature, low gradient temperature
- Fe17Cr compatibility with Zr-4 is proven at 600°C. Issue at higher temperature needs to be addressed for DBA.
- Need for evaluation and assessment of the
  - swelling laws (solid, pseudo-solid, gaseous and irradiation),
  - creep law (thermal and irradiation induced),
  - matrix stability (irradiation damage, particles swelling accommodation)
  - PCMI

  by in situ experiments.

Next steps...

- Fabrication PuO_2-Ferritic CERMET pellets
- Irradiation in MTR
- PIE
- Qualification in a PWR