CERMET PuO\textsubscript{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%

Reactivity behavior as a function of the irradiation time

Plutonium balance per PWR assembly

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

Kg Pu per assembly

0 10 20 30 40 50 60

Fresh spent

+5 Kg -11 Kg -25 Kg

PWR fuel type

Irradiation days

K-infinity

0 200 400 600 800 1000 1200

UO2

MOX 8%Pu

CERMET 15%PuO2

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Fabrication test: Powders

**Ferritic Stainless steel powders**
- Gas-atomized
- Water-atomized

**CeO₂ powders** *(surrogate for PuO₂)*
- Micronized CeO₂ powder
- Granulated CeO₂ powder

- D = 12 µm
- D = 60 µm
- 71-125 µm
Fabrication test: Pellets

- CeO₂: 10 wt% (↔ 15 wt% PuO₂)
- FeCr: 90 wt%

Binder

Lubricant

Mixing

Pelletizing (Standard conditions)

Sintering
1400°C - Ar / 5%H₂

- 90-95% TD
- high stability
- no grinding
Fabrication test: Microstructure

dispersed CERMET

Water-atomized stainless steel

Gas-atomized stainless steel

granulated CERMET

Gas-atomized stainless steel

EPMA
Pellet-Cladding compatibility

600°C/150h under Ar

Zr-4 → Cermet

EPMA on contact surface

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
Cp measured and deduced using Neumann-Kopp rule

Thermal Conductivity

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

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

Tmax: 520°C  
Tmin: 420°C

von Mises [Pa]

% VOLUME INCREASE IN UO2

%B.U. U atoms

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

As fabricated radial gap = 85 µm

Gap closure

Time (days)

Radial gap (µm)

Linear power (W/cm)
Thermo-mechanical Evaluation

Fuel rod temperature

![Graph showing central temperature and linear power over time for different materials: CERMET, MOX, UO2. BOL and EOL conditions are indicated with specific temperatures.]
Thermo-mechanical Evaluation

Achieved Burnup:  CERMET ~250 GWd/tox
                 MOX-UO₂ ~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