High-Temperature Experimental Techniques for Nuclear Fuel Separate Effect Tests

30/10/2019 SYP - Janne Heikinheimo

Outline

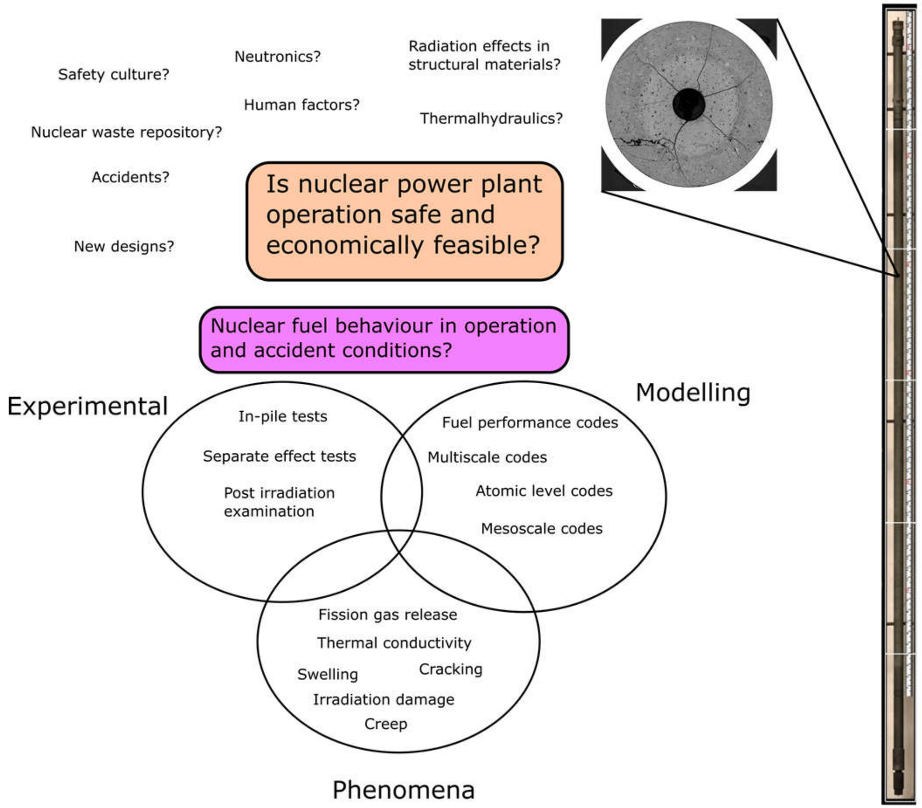
- Why separate effect tests are required for nuclear fuels?
- Furnace for UO_2 separate effect tests
- Uranium oxide properties – oxygen partial pressure
- Example: nuclear fuel aerosol particle preparation
- Future plans

Why separate effect tests are required for nuclear fuels?

30/10/2019 SYP - Janne Heikinheimo

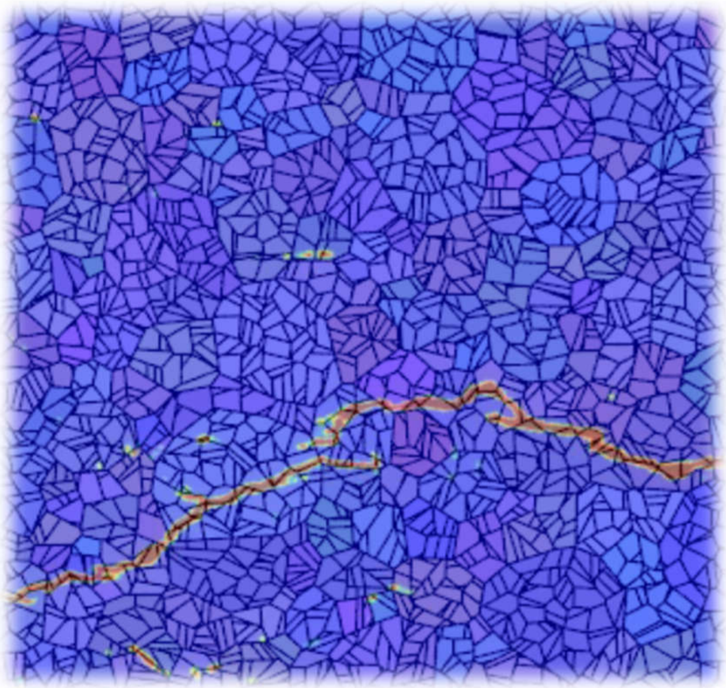
Full-scale experiments and macroscopic modelling

- Full-scale experiments in reactor conditions
  - The behaviour corresponds the actual fuel behaviour
  - The origin of many phenomena cannot be explicitly studied
- Macroscopic modelling
  - Works well with the validated cases
  - Cannot model accurately phenomena arising from the microstructure
  - May not be reliable in predicting the fuel behaviour beyond the validation data



Separate effect tests and microstructural modelling

- Separate effect tests connected to microstructural characterization
  - Recognize the cause for a phenomenon
  - Improve model predictions
- Microstructural and/or multiscale modelling
  - Takes into account microstructural development and inhomogeneities in the structure
  - Utilize more physics based approach to fuel simulations compared to the macroscopic modelling
  - Computationally heavy

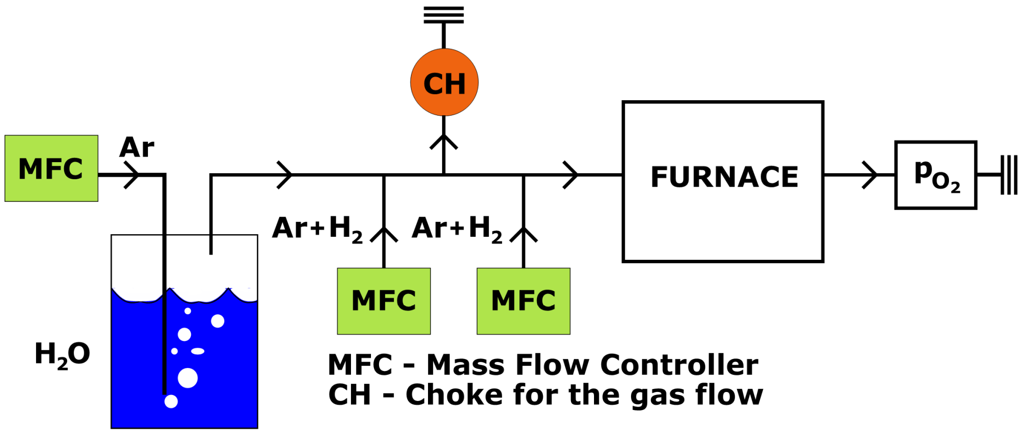


Experimental

Furnace for UO_2 separate effect tests at VTT Centre for Nuclear Safety

- Sample preparation:
  - Sintering at 1700 °C in H_2 + Ar atmosphere to obtain stoichiometric UO_2
- Possible separate effect tests for UO_2 pellets:
  - Oxygen partial pressure adjustment
  - Temperature effects: thermal diffusion of elements, precipitation, cracking
- Microscopy characterization of the samples with SEM or TEM

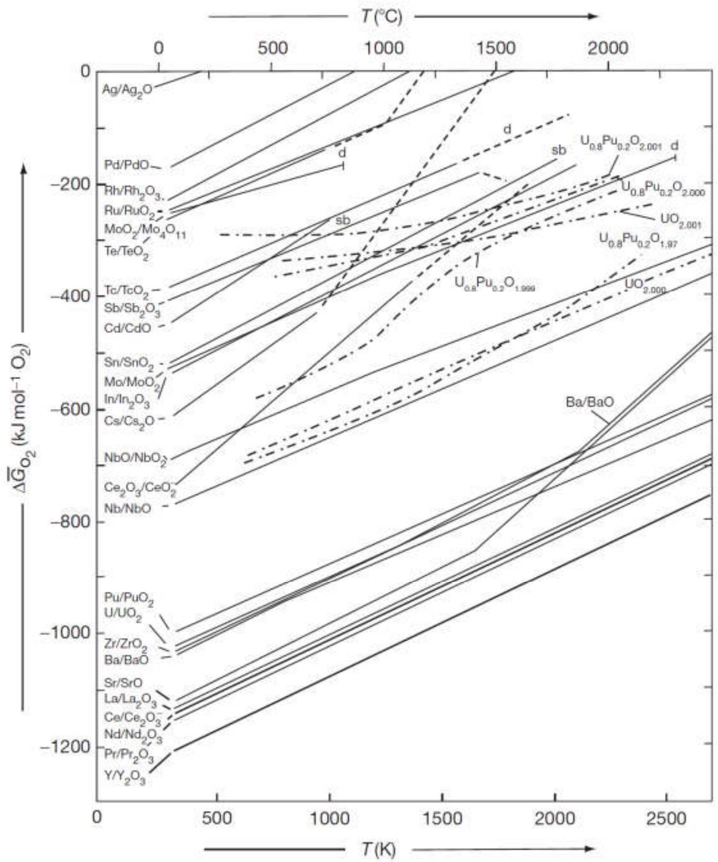
Uranium oxide properties – oxygen partial pressure



MFC - Mass Flow Controller
CH - Choke for the gas flow

$$p_{O_2} = \left(\frac{p_{H_2O}}{p_{H_2}} \exp\left(-\frac{\Delta G_0}{RT} \right) \right)^2$$

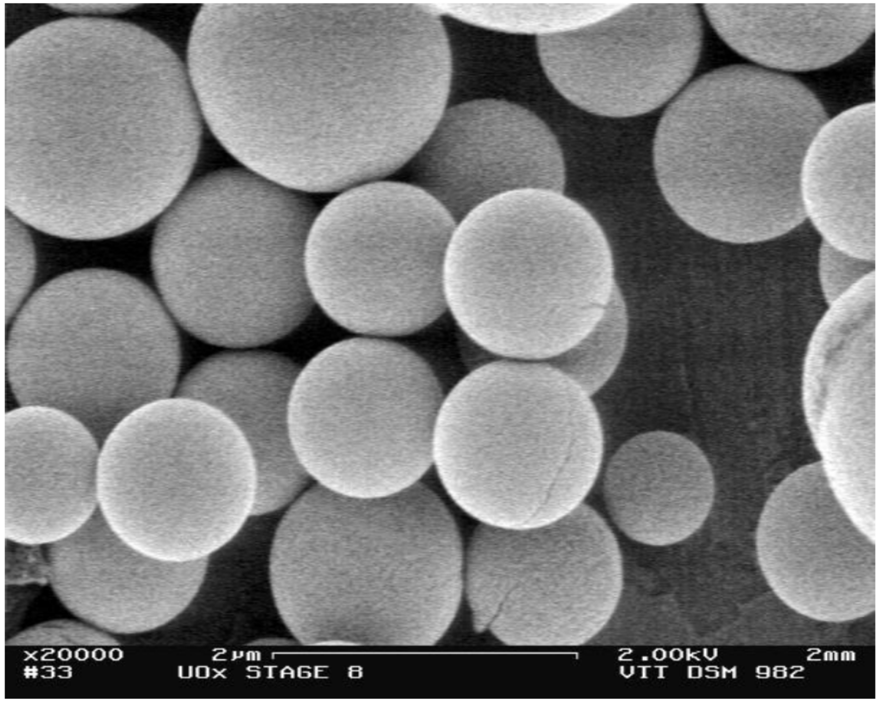
$p_{O_2} = 6\text{e-}9$ bar $\quad\quad p_{H_2O} = 1.5\text{e-}7$ bar



© Kleykamp, JNM 131:221, 1985

Example: nuclear fuel aerosol particle preparation

- U and Pu oxide particles for safeguard purposes
- Formation of oxides in the furnace
- Separation by size with Berner Low Pressure Impactor
- Particle average diameter 1 µm



Future plans

- Start UO_2 and simulated nuclear fuel sample annealings in hydrogen atmosphere
- Initiate separate effect tests, first concentrating on a single effect, for example
  - Implications of oxygen partial pressure on the crystal structure and properties
  - Thermal diffusion of elements / particles in the fuel, precipitation
  - Cracking under temperature loads
- Apply microscopy studies along with the separate effect tests
  - Sample preparation for alpha-active materials

VTT

beyond
the obvious

Janne Heikinheimo
janne.heikinheimo@vtt.fi

@VTTFinland

www.vtt.fi

30/10/2019