NE 591: Advanced Reactor Materials

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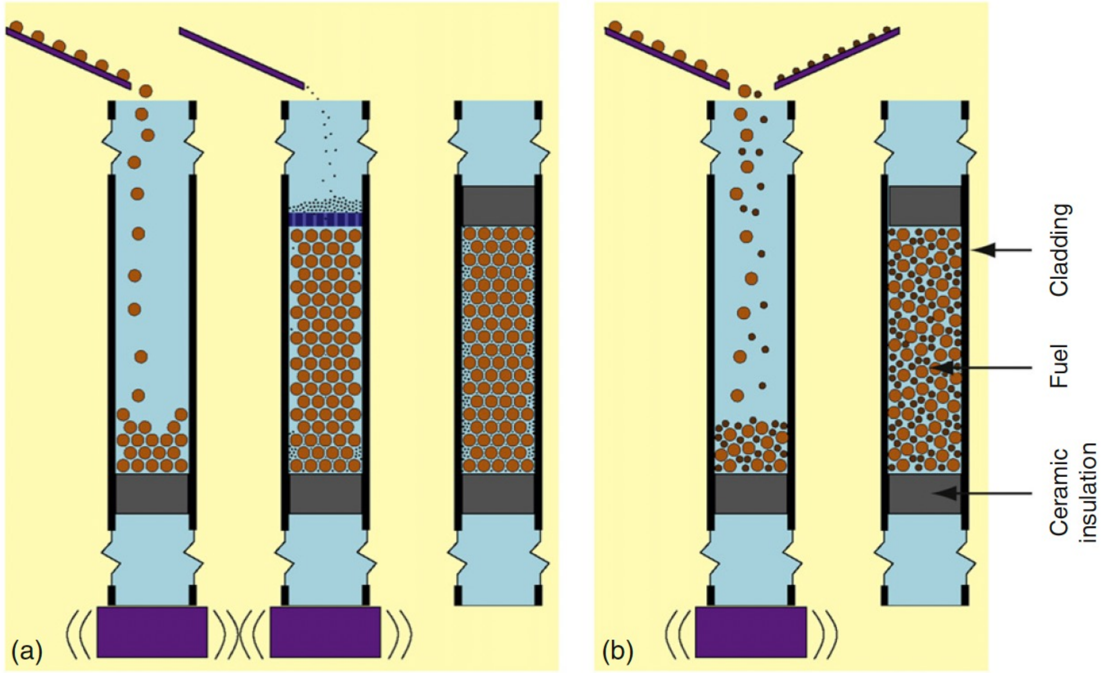
PARTICLE FUELS

Macrostructure Changes

- The macrostructure of the fuel changes with operation
- The high temperature will lead to sintering and restructuring into different zones (as in MOX fuel)
- Similar four zone restructuring will occur, but with different zones
- 1: central void; 2: highly dense fuel similar to a pellet; 3: sintered microstructure with retained porosity; 4: original particle macrostructure
- As the structure of the fuel changes, the properties change dramatically with radius and time

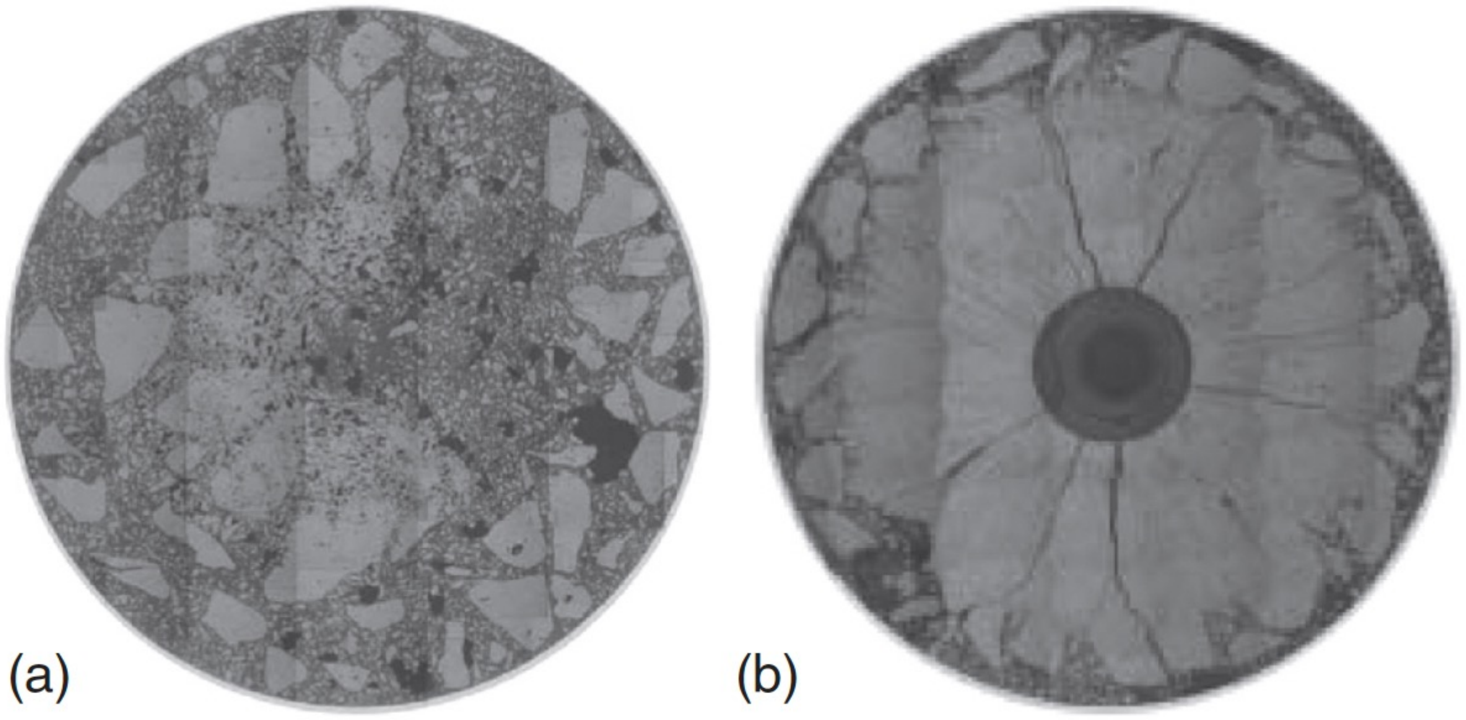
Sphere-Pac Concepts

- While the sphere-pac concept is more complex than vipac, it offers additional flexibility
- Particle sizes and particle distributions can be included
- Spherical particles offer low friction resistance during the filling procedure
- Sphere-pac can thus reach up to 90% smear density
- Infiltration filling (image a) allows for tailoring of small particles to serve specific purposes, such as an oxygen getter, a low reactivity with cladding, etc.



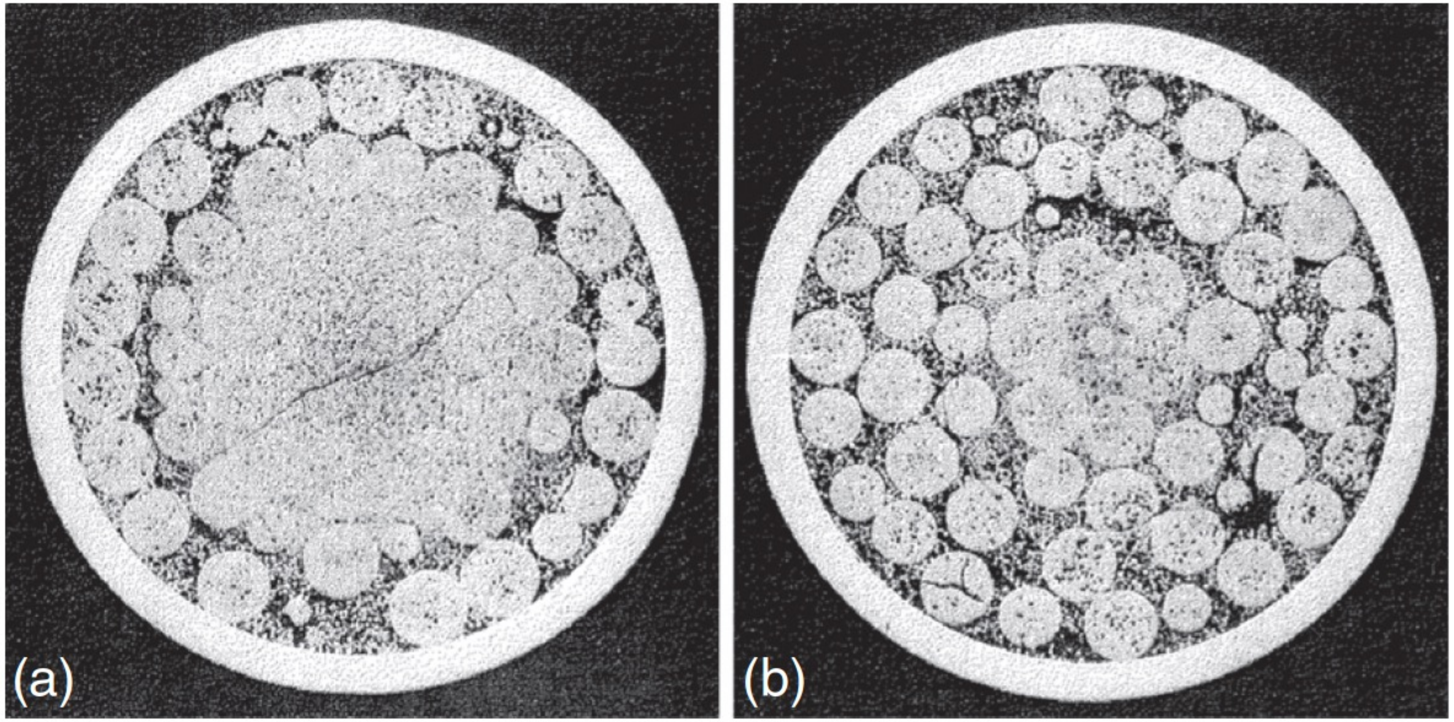
Vipac Irradiations

- Japanese irradiations (FUJI Project), with MOX fuel 20% Pu
- Vipac fuel after initial sintering test irradiated up to 487 W/cm after 36h
- Restructuring test with ramping up to 502 W/cm for 36h and holding at 502 W/cm for 96h



Sphere-Pac Irradiations

- Dounreay fast reactor – UPu-C fuels
- a) 62 kW/m, 7.3% FIMA, 458C
- b) 49 kW/m, 5.7% FIMA, 320C



Overview

- Particle fuels are a realistic option for fast reactor systems
- Fast reactors allow for efficient burning of actinides
- Nominal fast reactor fuel pins are designed for fission gas release, and thus the larger gas release, compared to UO2, is not detrimental
- Other fuel bases, other than oxides, can easily be deployed
- FCMI is greatly reduced due to the inherent space allowing for swelling of the particles
- LWR application is limited

WASTE GLASSES

Waste Forms

- Fission products (FPs) and minor actinides (MAs) produced during fuel irradiation in the reactor only represent about 5% of the weight of used nuclear fuel, but about 98% of its radioactivity
- When fuel is reprocessed, the FPs and MAs end up in concentrated solutions (High Level Waste – HLW) temporarily stored in tanks
- Long term (>100 year) storage requires a different path, with initial targets on glass or glass-ceramics to immobilize FPs
- The first attempts at the CEA in 1957 targeted crystals of mica-phlogopite: $M_2Mg_6(AlSi_3)_2O_{20}F_4$
- Twenty years later, borosilicate glass had appeared as the standard choice for the HLW matrix

Glasses

- Some liquid phase materials have a high viscosity near the melting point, and such materials tend to crystallize slowly
- If a cooling rate is faster than the crystallization rate, the material will rigidify into a “vitreous state”, in which no periodic crystal structure is present
- Glass has an absence of order in the distribution of elementary structural units at scales larger than 10–30 Å
- Glass is in a metastable state, but is not unstable because the energy barrier to bring it to its more stable crystallized state is generally significant due to the high viscosity
- Glass is a non porous, impermeable, isotropic, non cleavable, elastic, solid with a fragile rupture behavior
- Glass is a material which transitions continuously and reversibly from liquid to solid state with temperature

Waste Glasses

- Vitrification consists of making a new material where the waste components are contained at the atomic scale within the matrix and can only be released by destruction of the network bonds
- One major requirement is then that the selected matrix be able to incorporate all of the waste stream components in its structure
- By using the flexibility brought about by the disordered and relatively loose structure of a glass, it is possible to design glass compositions able to integrate a very wide range of elements within their structure, and which are tolerant to compositional variations in the waste stream

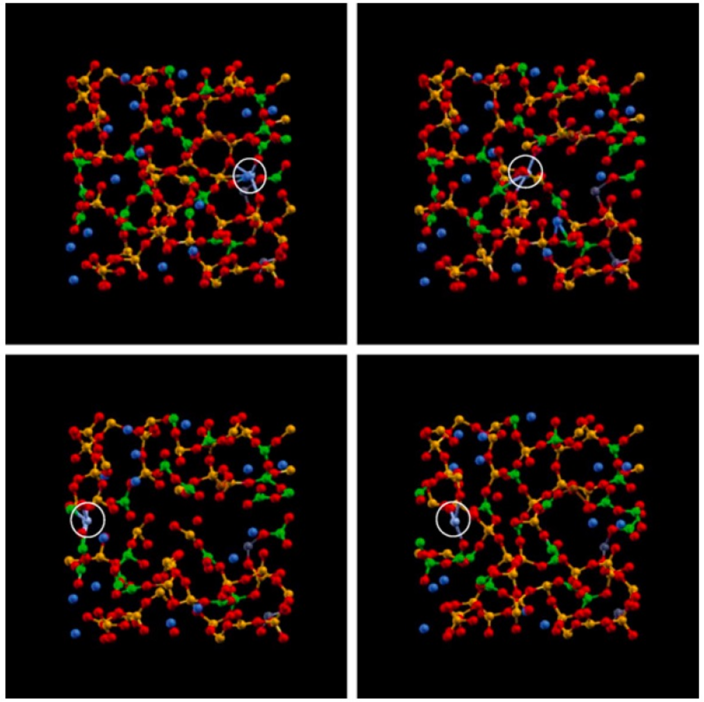
Behavior of Waste Glasses

- The main phenomena that could alter glass containment properties over the long term are heat (for HLW only), radiations damage and alteration by water
- Heat can potentially induce the glass to reach a point beyond the glass transition temperature
- However, in nuclear glasses the diffusion is sufficiently slow (high viscosity) to make crystallization incredibly difficult
- In the R7T7 glass, a period of several millions of years are required for the three main phases to be completely crystallized at any temperature below 600C

Radiation Damage

- Alpha decay is the main cause of radiation damage, where a radioactive nuclide emits an alpha particle (He atom) and a recoil nucleus, generating damage cascades
- Due to the effect of alpha decay the glass density decreases slightly, and its mechanical properties improve, especially fracture toughness

- MD simulations have been performed that show the capacity of glasses to restore its structure following a cascade event



Waste Glass Summary

- Vitrification is the world reference solution to the containment of HLW
- Glasses can easily incorporate all known fission product species
- Glasses will not undergo crystallization due to decay heat
- Glasses self-heal irradiation damage
- Glasses are reasonably resistant to long-term exposure to sea water

QUESTIONS?