Chapt. 10 Fuel Element Performance

10.1) Important Features

Oxide fuel characteristics

- ***Temperature (T_{max}≈2800 °C)***
  - ***Sintering***
  - ***Grain growth***
  - ***Diffusion***
- $\dfrac{\Delta T}{\Delta x}$
  - ***Stress***
  - ***Pore closing***
  - ***FP redistribution***

10.1.1) Oxide Fuels- (started ≈ 1955)

(Fig/Table)

Most important properties of mixed oxides depend on the O/M ratio

$$q = \frac{N_{pu}}{\sum N_{\text{heavy metal}}}$$

$$x = \frac{N_{ox}}{\sum N_{\text{heavy metal}}}$$

for example…… $(U_{1-q}Pu_q)O_{2\pm x}$

Hyper<u>er</u> stoichiometry $O/M > 2.00$

Hyp<u>o</u>stoichiometry $O/M < 2.00$

Disadvantages of Oxide Fuels

1.) Low U density (larger core)

2.) Low thermal conductivity
(requires thin rods, produces high T)

Why not use UC, UN, UP, US, etc.?

10.1.2 Fission Properties

<u>Burnup</u>

$$\beta = \frac{\text{Number of Fissions}}{\text{Initial Number of Heavy Metal Atoms}}$$

<u>Rule of Thumb</u>

$$1 \text{ at\% B.U.} \approx 10{,}000 \frac{MWd}{MtU} \quad @\, 200 \frac{MeV}{fission}$$

Fissioning of 1 g of fissile material ≈ 1MWd

Maximum burn up with no Pu credit;

- ***Natural U*** $6650\ \frac{MWd}{MtU}$
- ***15% enriched*** $142{,}500\ \frac{MWd}{MtU}$

Major Differences Between LWR & LMFBR Fuels

	LWR	LMFBR
Ave neutron energy, eV	0.03	500,000
Fissile isotope	^{235}U	^{239}Pu
σ_f, barns	550	1.8
Neutron flux, (rel)	1	300
Power density, (rel)	1	3 (why?)
Burn up, %	3	10
Enrichment, %	3	15

Differences Between LWR and LMFBR Fuel Assemblies

	LWR	LMFBR
Damage to clad	1	100
Fuel pin diameter, mm	11	6
Core fuel fraction	-	Higher
Cladding	-	Hotter
Size of Core	-	Smaller (no moderator needed)

See Table 10.2 and figures 10.1 thru 10.4

10.2 Thermal Properties

10.2.1 Melting Points

T_{MP} of UO_2 = 2865 °C

(2847 °C in some papers)

Several Factors Influence the Melting Point

- *Stoichiometry (phase diagram)*
- *Mixed Oxide ,UO_2 -PuO_2 , (2 figs see correc.)*
- *Burn -Up (figure + table)*

10.2.2 Thermal Expansion

Problems -Cladding stress, Poor heat transfer

Stoichiometry Effect-Figure 10.8

10.2.3 Specific Heat (See Chapter 1)

(Important for dynamic behaviour, $\frac{k}{\rho C_p}$)

thermal expansion   Molar Volume

$$C_p = \left(\frac{\delta H}{\delta T}\right)_p = C_v + \left(\frac{\alpha^2 V}{\beta}\right)T$$

compressibility

Figure 10.10

Corrections to Olander Book
from Nuclear System Handbook (NSH)

Melting Point, °C

Mole Fraction PuO_2	Solidus	NSH Liquidus	Liquidus Olander
0.0	2847	2847	2865
0.2	2728	2767	
0.4	2632	2685	≈2700
0.6	2553	2600	≈2600
0.8	2487	2530	
1.0	2428	2428	≈2360

Density:

$$\rho = \frac{\text{MW metal atoms}}{\text{MW nat. U}} \left[5875.5 + 4.97(\%PuO_2) + 2540\frac{O}{M}\right] \frac{kg}{m3}$$

Effect of Burnup on MP of Mixed UO_2-PuO_2

For 20-25% PuO_2
from NSH

Burn up MWd/MtU	Change in Melting Point °C
15,000	-62
25,000	-64
50,000	-69
75,000	-74
100,000	-80

Table 10.2 Comparison of Fuel Element Characteristics		
	Thermal Reactor	**Fast Reactor**
Fuel	**UO_2**	**$(U,Pu)O_{1.96}$**
Fuel Pellet Density (% of theoretical)	**92**	**90**
Max. fuel centerline temperature (overpower condition)°C	**2450**	**2800**
Cladding	**Zircaloy-4**	**316 Stainless Steel**
Max. cladding mid-wall temperature °C	**380**	**660**
Coolant temperature, °C	**H_2O, 280-320**	**Na, 470-650**
Maximum rod linear power, W/cm	**620**	**550**
Fuel wrapper assembly	**Square, 30x30**	**Hexagonal, 13 cm across flats**
# of pins in assembly	**200**	**220**
Fuel-rod outside diameter, mm	**10.7**	**6.3**
Cladding thickness, mm	**0.6**	**0.4**
Initial fuel-cladding radial gap, mm	**0.08**	**0.07**
Length of fueled portion, cm	**365**	**90**