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Fundamentals of Nuclear Fuel Cycle

Lecturer
Andrey O. Semenov

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Fuel

Fuel types	Example
Carbides	UC; UC_2; PuC
Nitrides	UN; PuN
Metallic	U; ligated U
Mixture	PuO_2+UO_2
Oxides	UO_2;PuO_2;U_3O_8
Solts	$PuCl_x$; UCl_x

Fuel pellets specification

87.7% uranium

Total impurities 1500μg/g

Equivalent Boron Content (EBC) < 4.0 μg/g (B, Gd, Eu, Cd)

Dimensions (diameter, length, perpendicularity, surface finish)

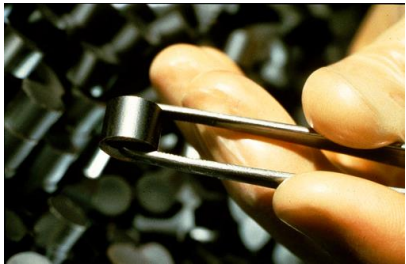
~1 cm x 1.2 cm (+/- ~0.001)

Density 95% of theoretical – 10.96 g/cm$_3$

Grain size and pore morphology ~30 μm

Cracks 1/2 the pellet length

Chips <5% of cylindrical area



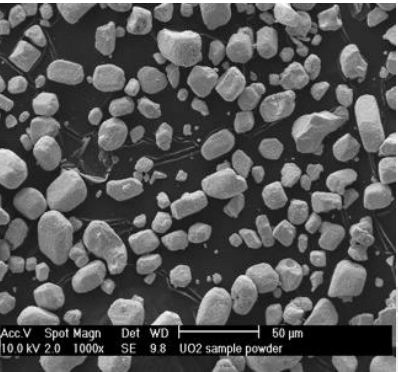
Stages of fuel fabrication

- Pellets production
- Fuel rods production
- Fuel loading into the roads
- Making fuel assemblies from fuel rods

Pellets production

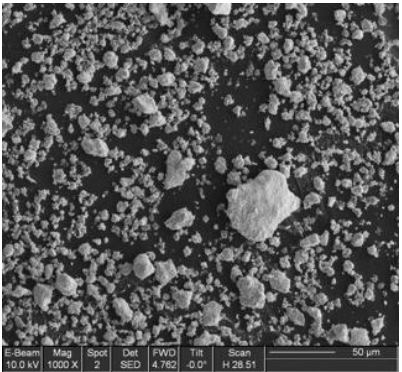
Powder synthesis
- ADU (ammonium diurinate)
- AUC (ammonium uranium carbonate)

Power conditioning
Compacting
Thermal treatment



AUC

ADU



AUC $NH_4(UO_2(CO_3)_3)$

Hydrolyze UF_6 with steam to UO_2F_2

⇩

Further hydrolyze with a dilute solution of NH_3 to form a precipitate of ammonium diurinate

⇩

Calcine to U_3O_8

⇩

Filter, dry, and heat in a gas atmosphere of H_2 and stream to form UO_2

Fuel fabrication

ADU $(NH_4)_2U_2O_7$

Evaporate UF_6 with steam

⇩

Precipitate AUC by injecting UF_6, CO_2, NH_3 as gases into demineralized water

⇩

Filter and remove water

⇩

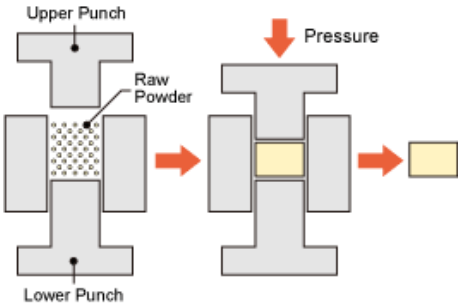
Wash with ammonium carbonate and methyl alcohol

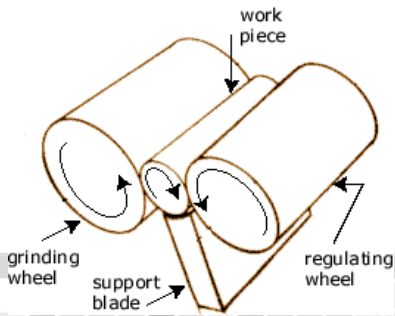
⇩

Calcine and reduce to UO_2 in a carrier gas atmosphere of H_2 and superheated steam

Pellets production

- UO_2 powder
- additives
- milling
- sieving
- pressing
- burnout
- sintering
- grinding





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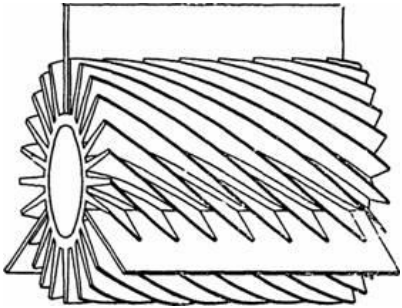
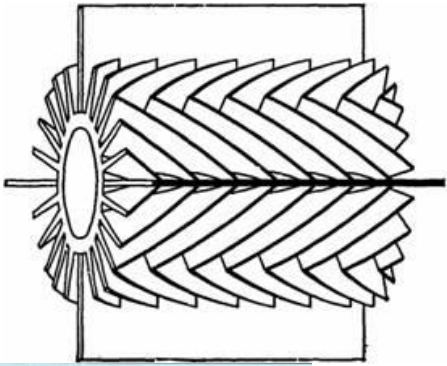
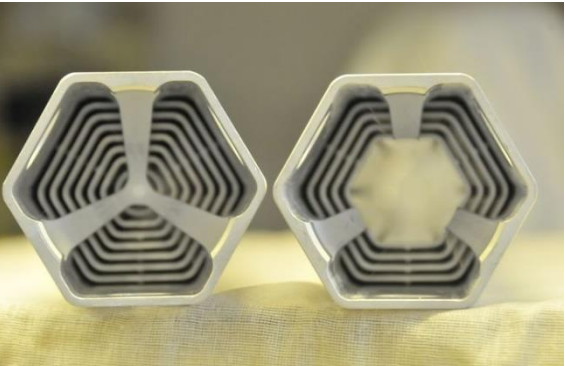
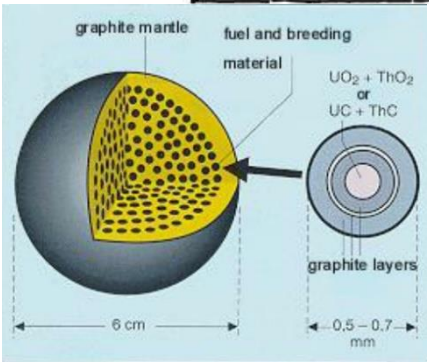
Fuel rods production



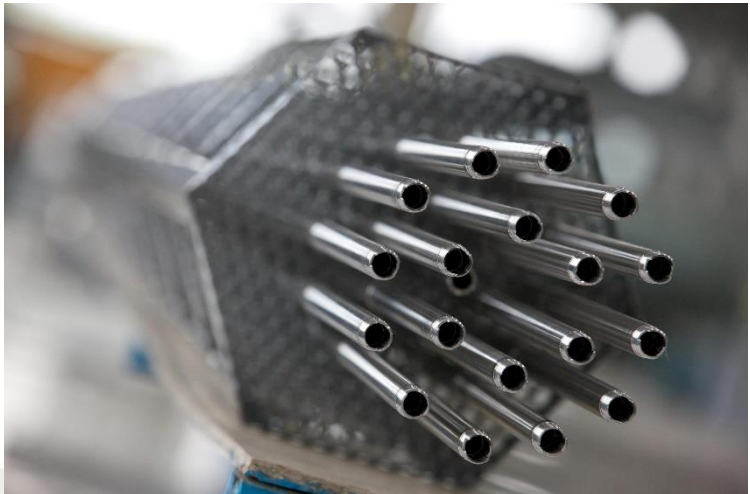






Fuel rods production

Zirconium alloys; chrome-nickel steel
Pressing at 650-1000 ºC
Pressurization by arc welding or ultrosaund



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Fuel assemblies

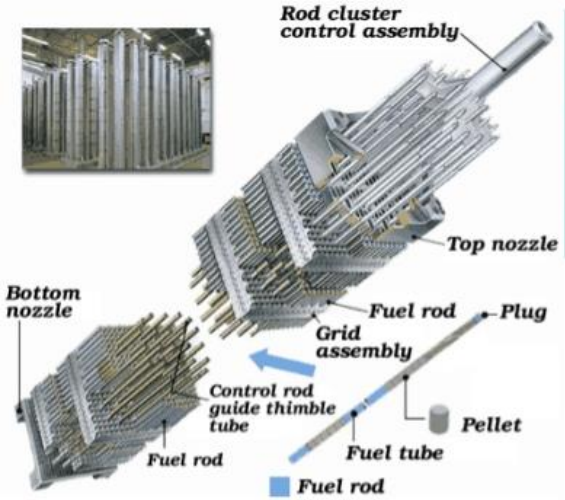
Fuel assemblies

Requirements

- Mechanical and dimensional stability
- Separate the fuel and fission products from the coolant
- Appropriate thermo-hydraulic properties
- Appropriate nuclear properties
- Be long lived without undue deterioration
- Be suitable for intermediate and final storage or reprocessing
- Allow removal of decay heat in accident conditions

Design features of LWR fuel assemblies

PWR Fuel Assembly



Sample PWR Fuel Assem

- Array of 14X14 rods
- 179 fuel rods
- 16 control rods - ganged
- 1 instrumentation rod
- Assembly is 7" X 7", 12 ft

Fuel: U-235 enriched fr
natural concentration of
0.71% to a few %

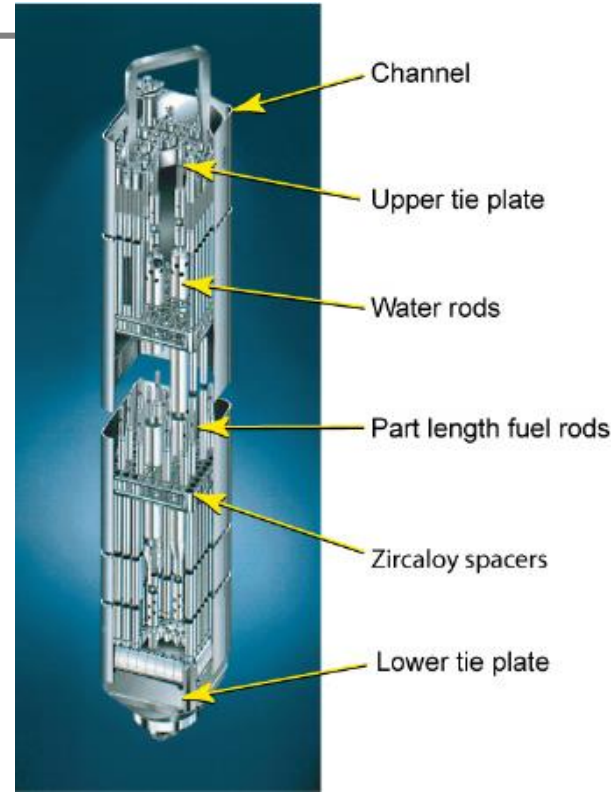
Fission of U-238 possibl
only with fast neutrons

T. Ferguson, University of

From http://www.mnf.co.jp/pages2/pwr2.htm. Accessed 2/28/08; and instructor notes

Design features of LWR fuel assemblies

BWR type



Dimensions of BWR and LWR fuel assemblies

Feature	PWR		BWR	
	14x14	18x18	9x9	10x10
Assembly length, mm	3900-4060	4830	4470	4420-4480
Assembly square width, mm	197-206	230	139	139
Rod length, mm	3730-3870	4390-4430	4075-4090	3890-4150
Number of fuel rods	176-179	300	72	91-96
Average heat rating, W/cm	204-220	166-167	158-160	124-158

Design features of VVER fuel assemblies