

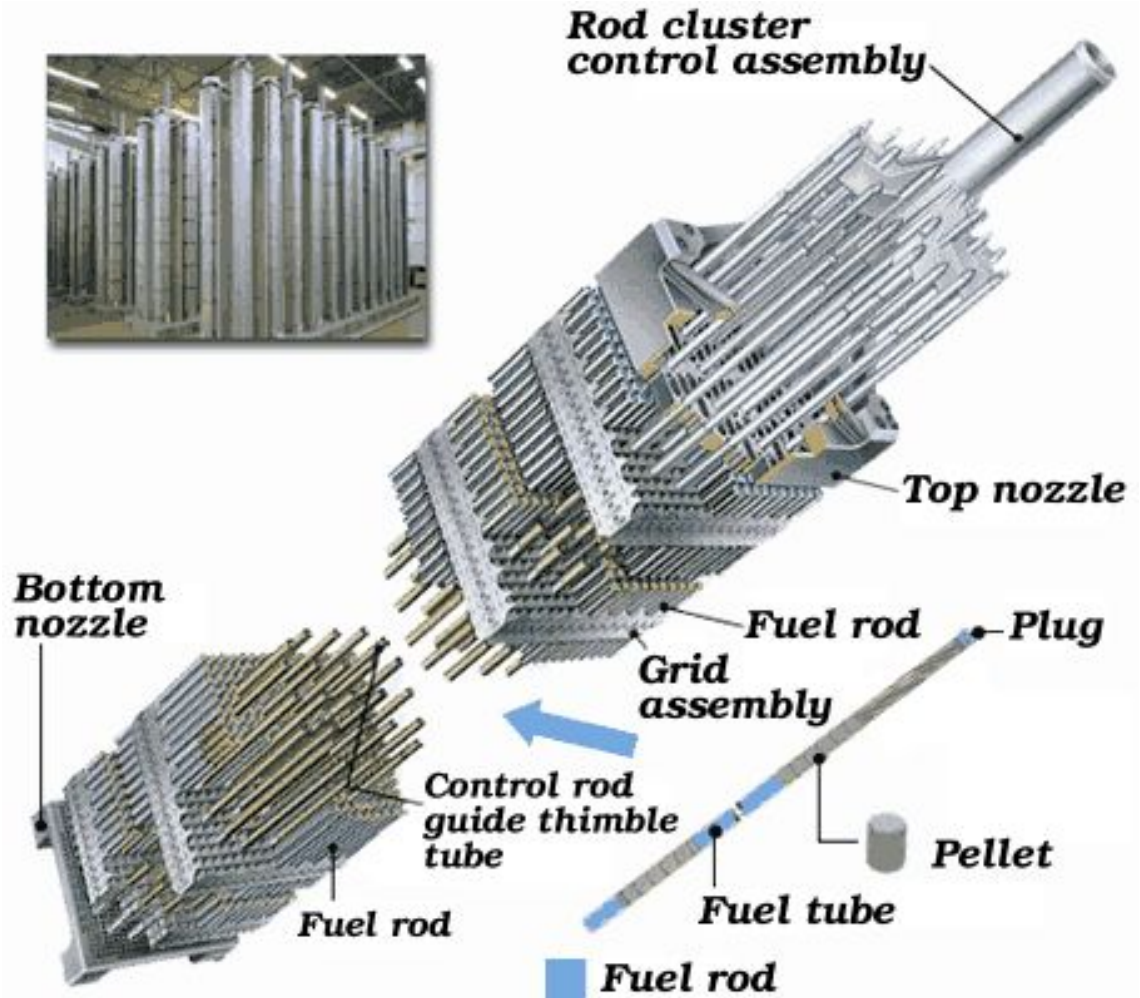
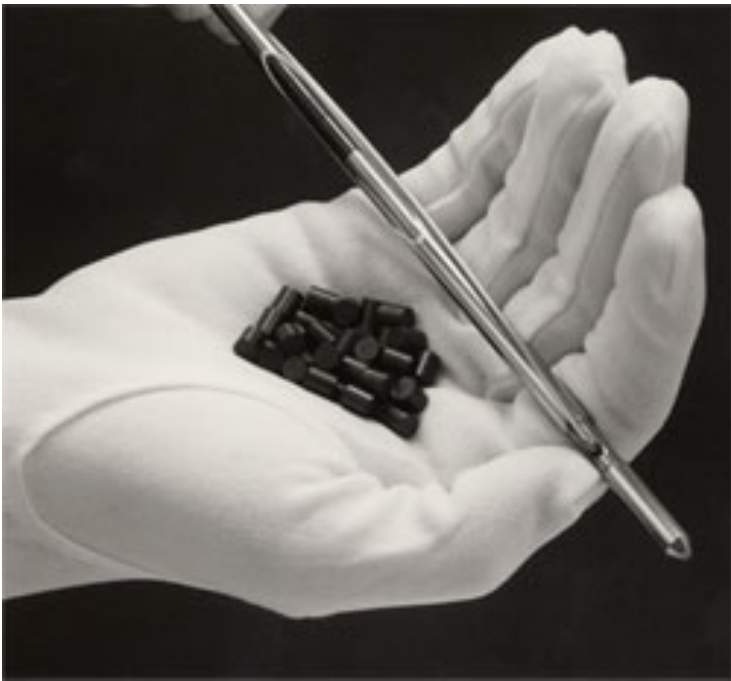
Nuclear Reactor Context

Rachel Slaybaugh
(derived from Vujic notes)

NE250

September 28, 2017

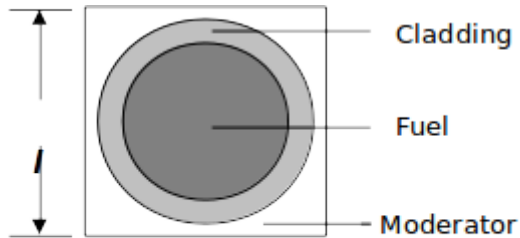
Nuclear Fuel Pellet, PWR Assembly



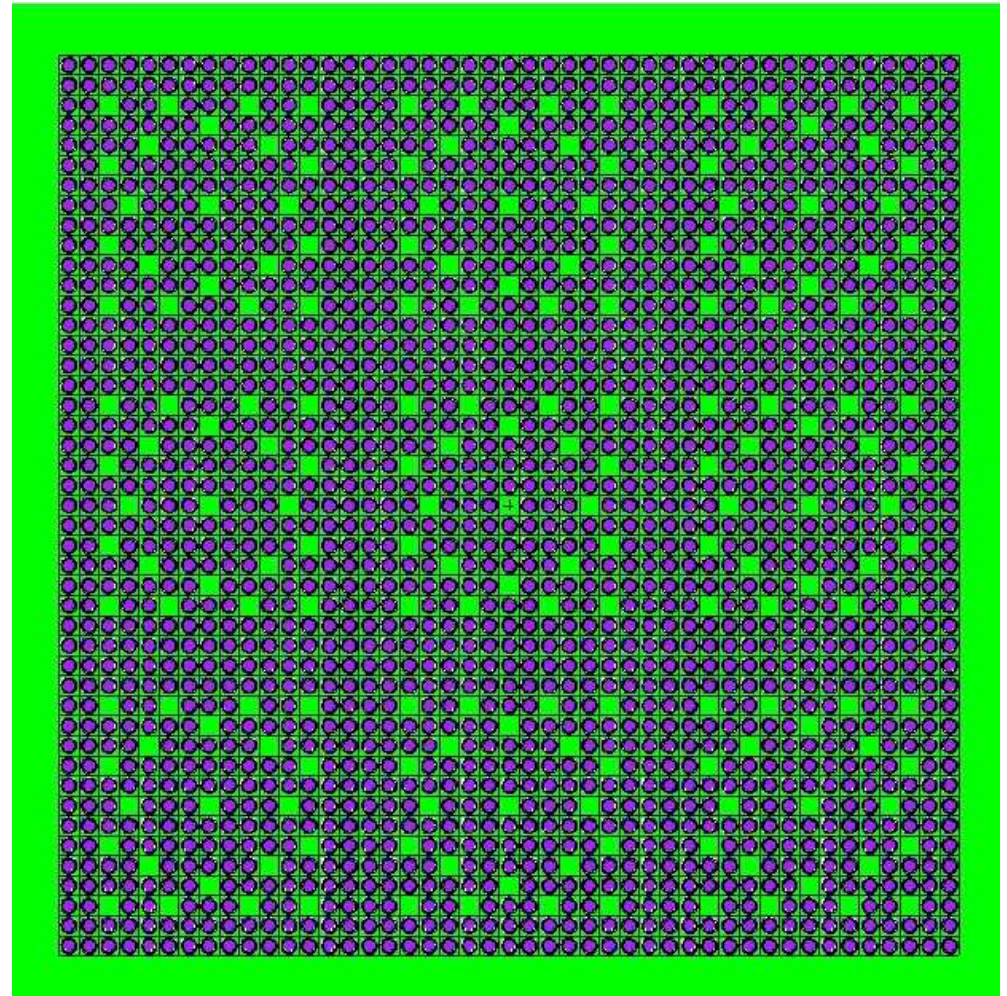
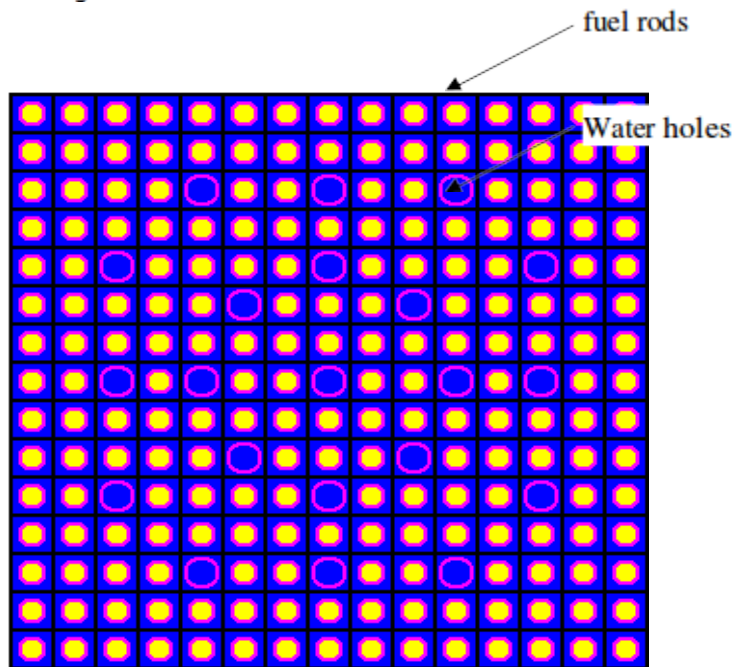
PWR Fuel Dimensions and Materials

- Dimensions: square, H=4.1m, 21cm x 21 cm
- Weight: 460 kgU, 520 kg UO₂, 135 kg hardware
 - Hardware mostly Zircaloy (Zr with Sn, Fe, Cr)
 - Grid spacers: Zircaloy, Inconel, stainless steel
 - End pieces: Stainless steel, Inconel
- Fuel element array: 14 x 14 to 17 x 17
- Fuel element size: 1 cm OD, H=3.9m
- Enrichment: 3-5%
- May have separate burnable poison rods

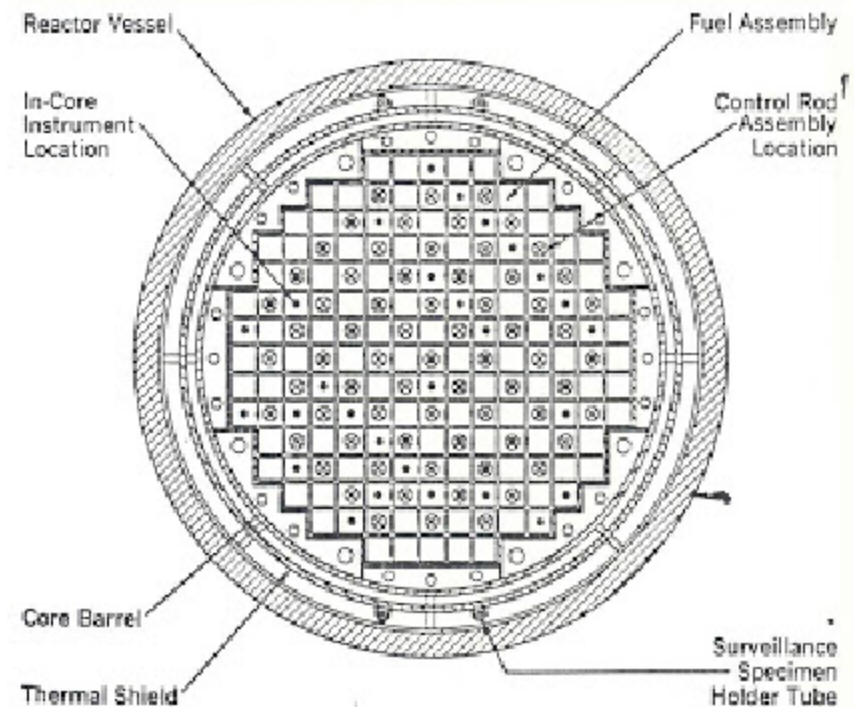
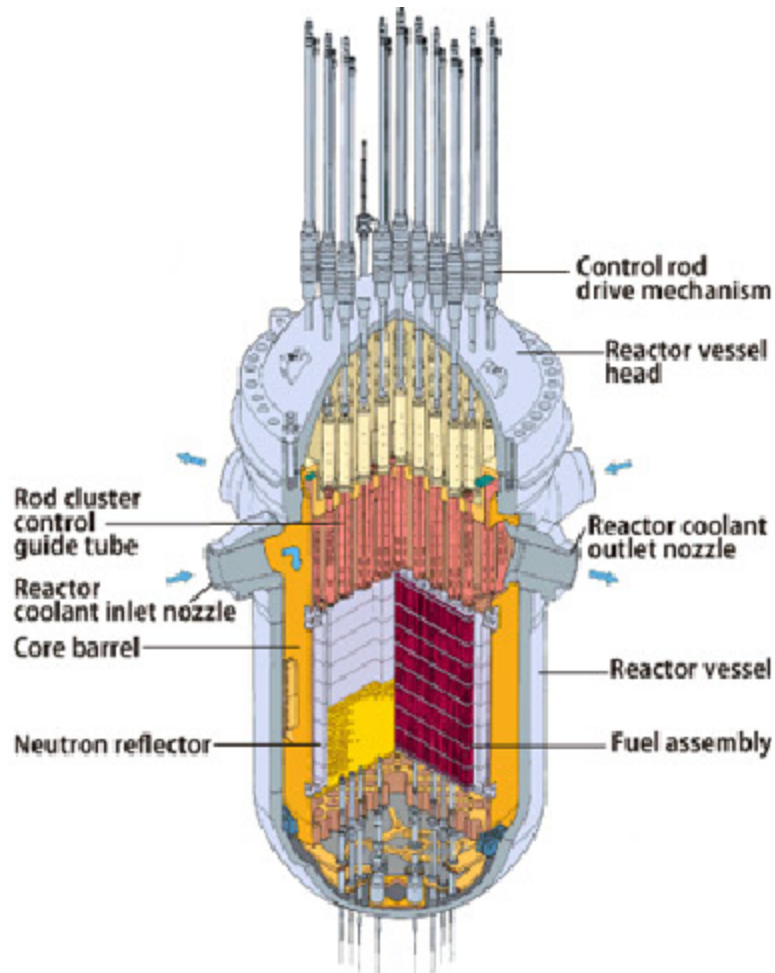
PWR Assembly Geometrical Variations



Cross-sectional view of single fuel cell.



Typical PWR Pressurized Reactor Vessel



Source: www.mhi.co.jp

BWR Fuel Assemblies

BWR/6 FUEL ASSEMBLIES & CONTROL ROD MODULE

- 1.TOP FUEL GUIDE
- 2.CHANNEL FASTENER
- 3.UPPER TIE PLATE
- 4.EXPANSION SPRING
- 5.LOCKING TAB
- 6.CHANNEL
- 7.CONTROL ROD
- 8.FUEL ROD
- 9.SPACER
- 10.CORE PLATE ASSEMBLY
- 11.LOWER TIE PLATE
- 12.FUEL SUPPORT PIECE
- 13.FUEL PELLETS
- 14.END PLUG
- 15.CHANNEL SPACER
- 16.PLENUM SPRING

GENERAL  ELECTRIC

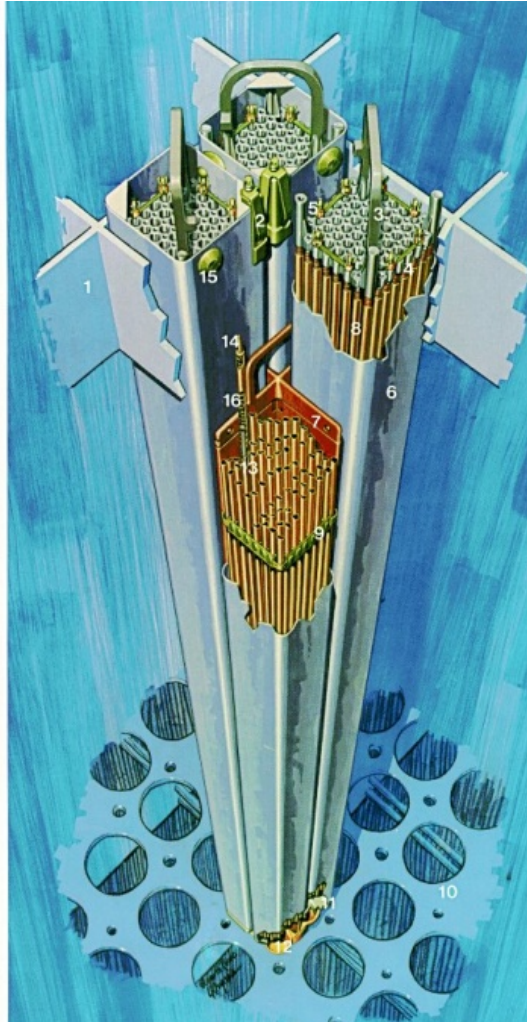
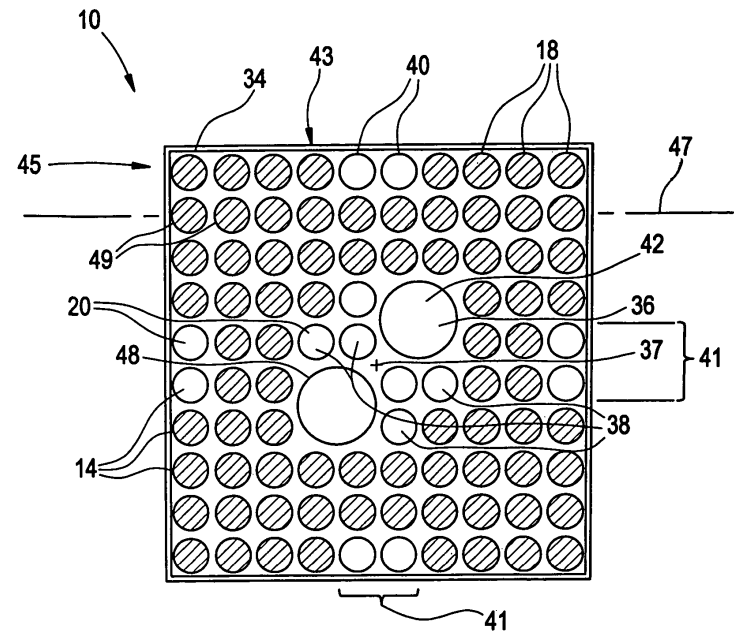


FIG. 2



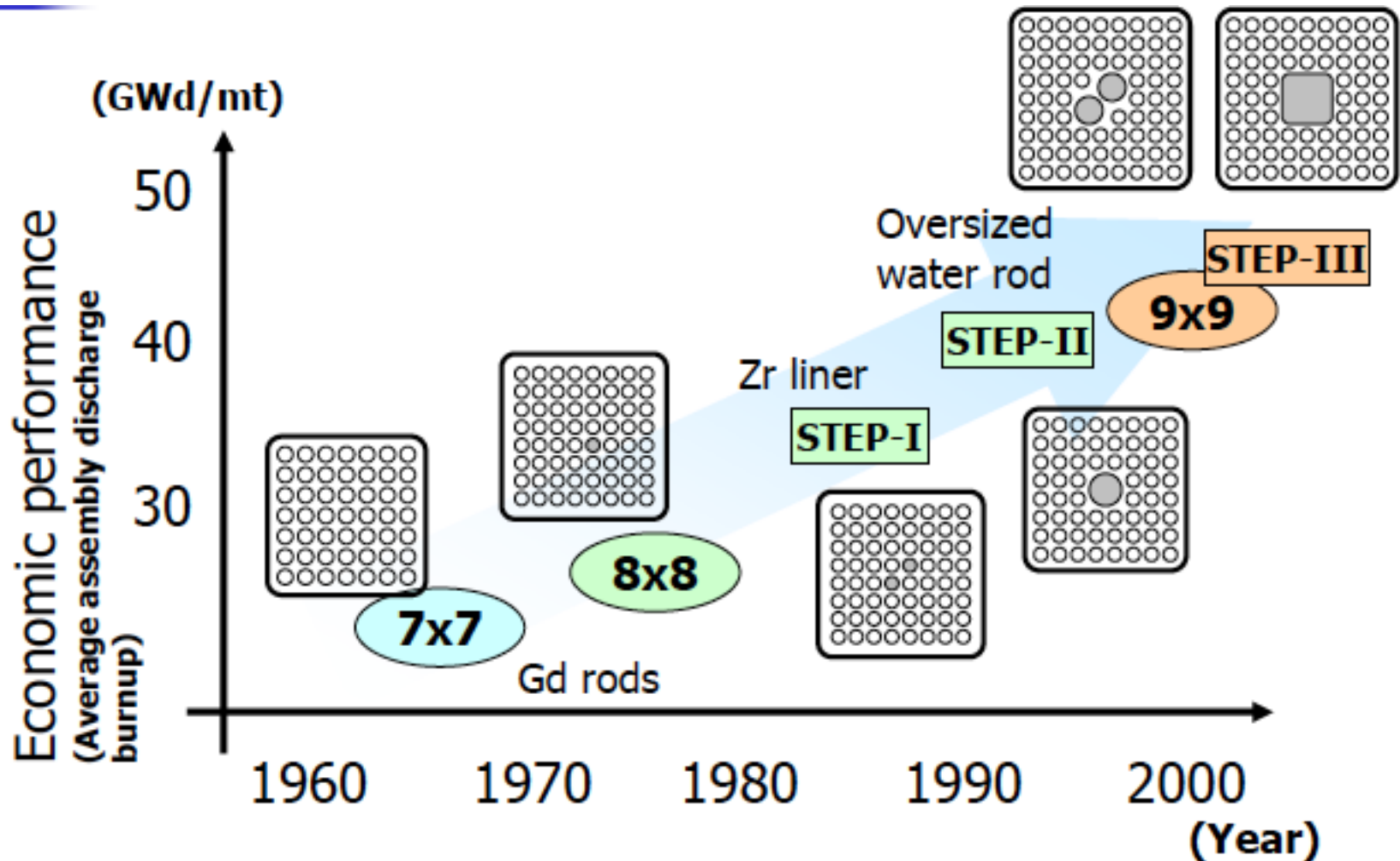
 Denotes Full - Length Fuel Rods

 Denotes Part - Length Fuel Rods

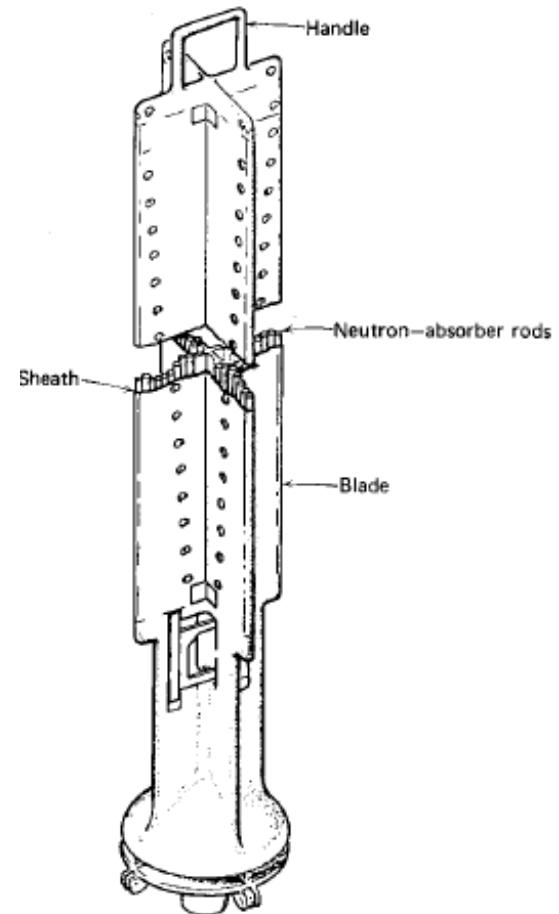
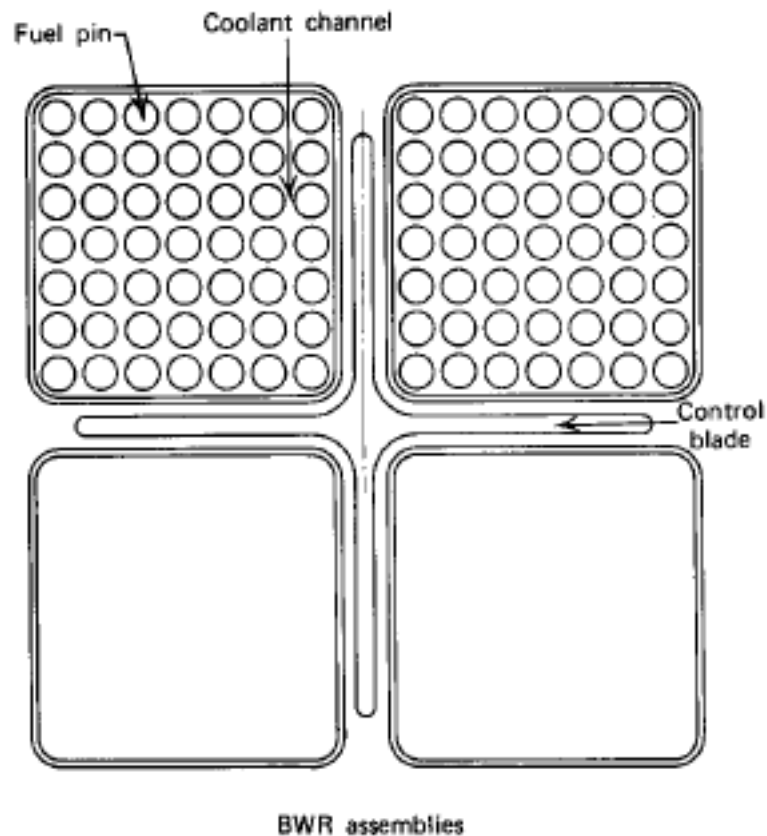
BWR Fuel Dimensions and Materials

- Dimensions: square, H=4.5m, 14 cm x 14 cm
- Weight: 180 kgU, 210 kg UO_2 , 110 kg hardware
 - Hardware mostly Zircaloy (Zr with Sn, Fe, Cr)
 - Grid spacers: Zircaloy
 - Channel (aka shroud): Zircaloy
 - End pieces: Stainless steel
- Fuel element array: 8 x 8
- Fuel element size: 1.25 cm OD, H=4.1m
- Enrichment: 2.5-4.5%
- May have Gd in some rods and variable enrichment in 3-D

History of GE BWR Fuel Assembly Designs

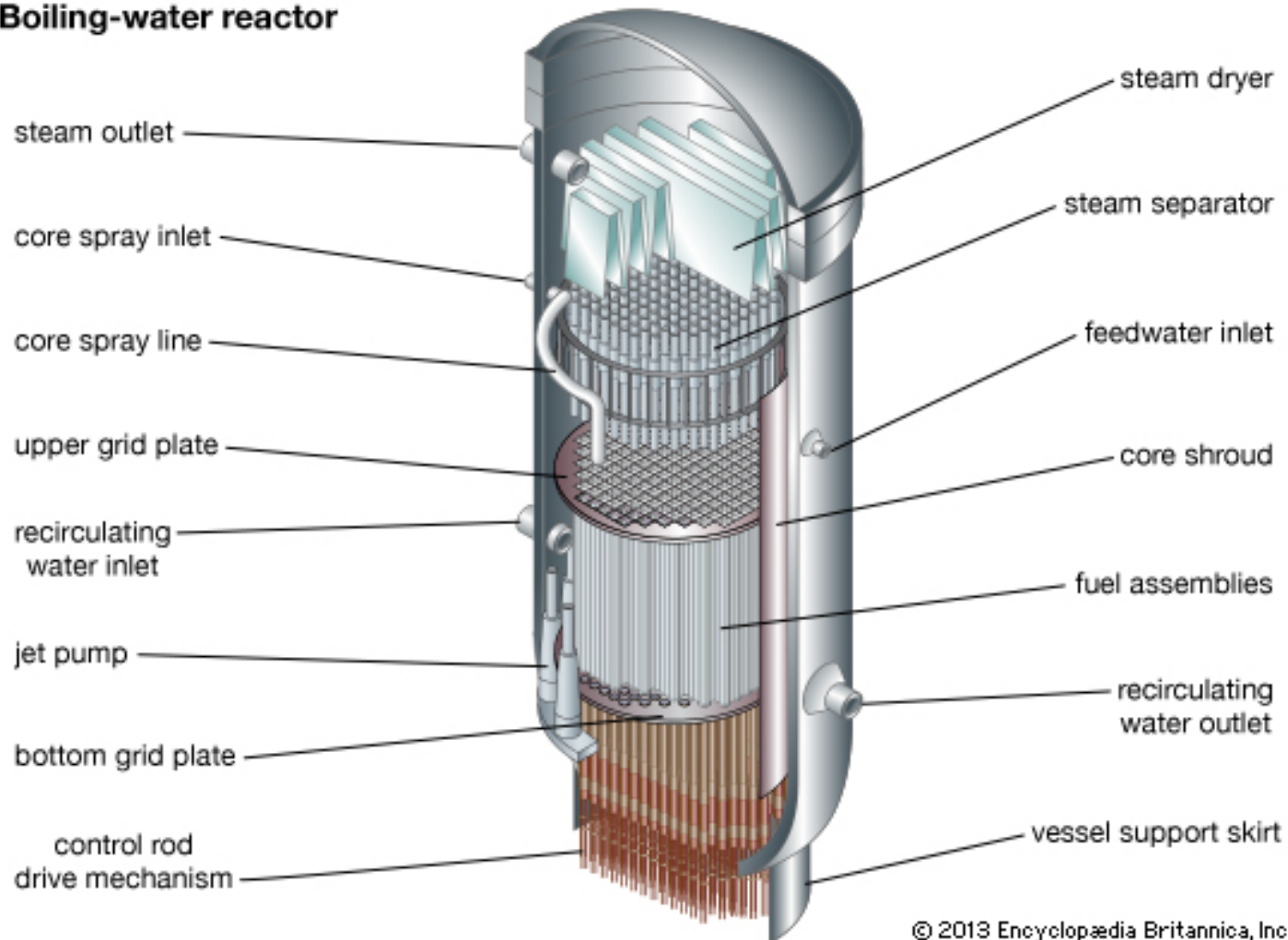


Four BWR Assemblies and A Cruciform Control Blade

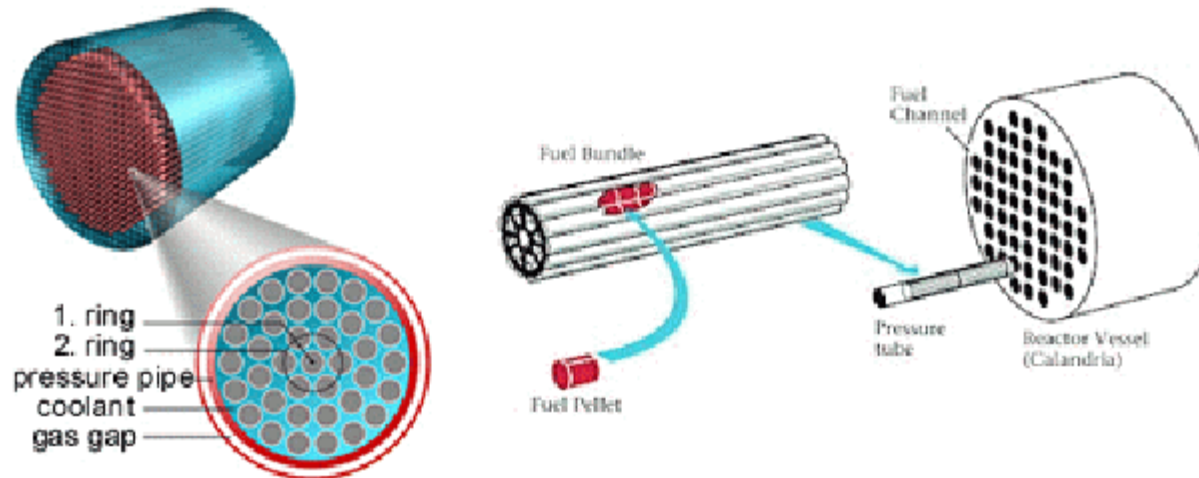


Boiling Water Reactor

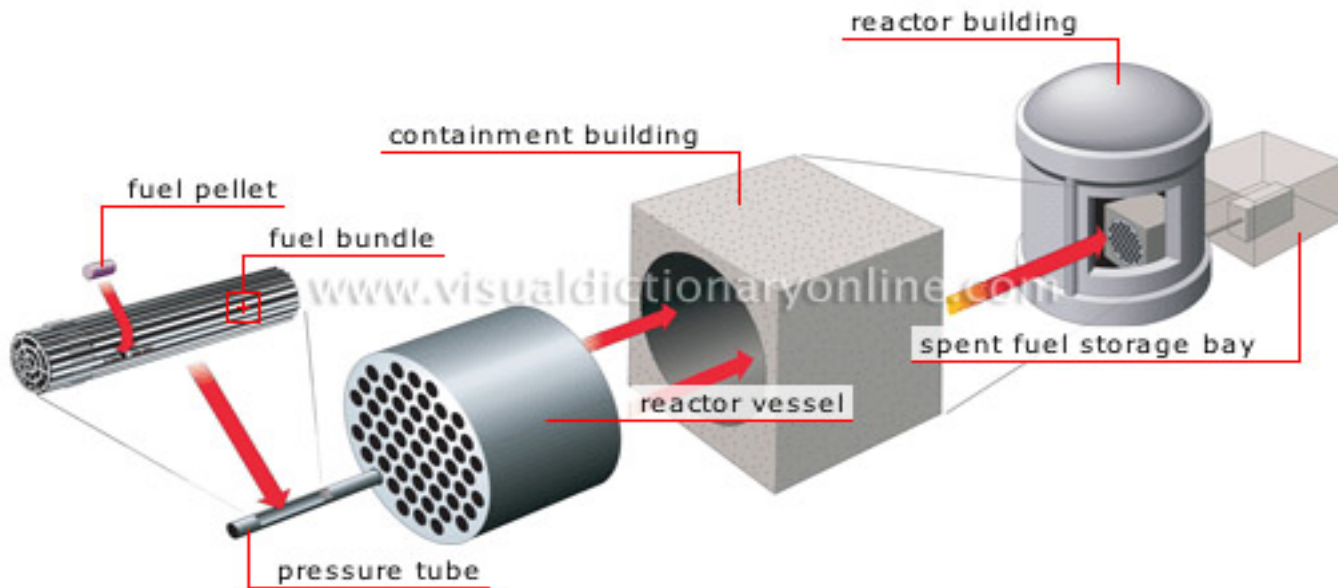
Boiling-water reactor



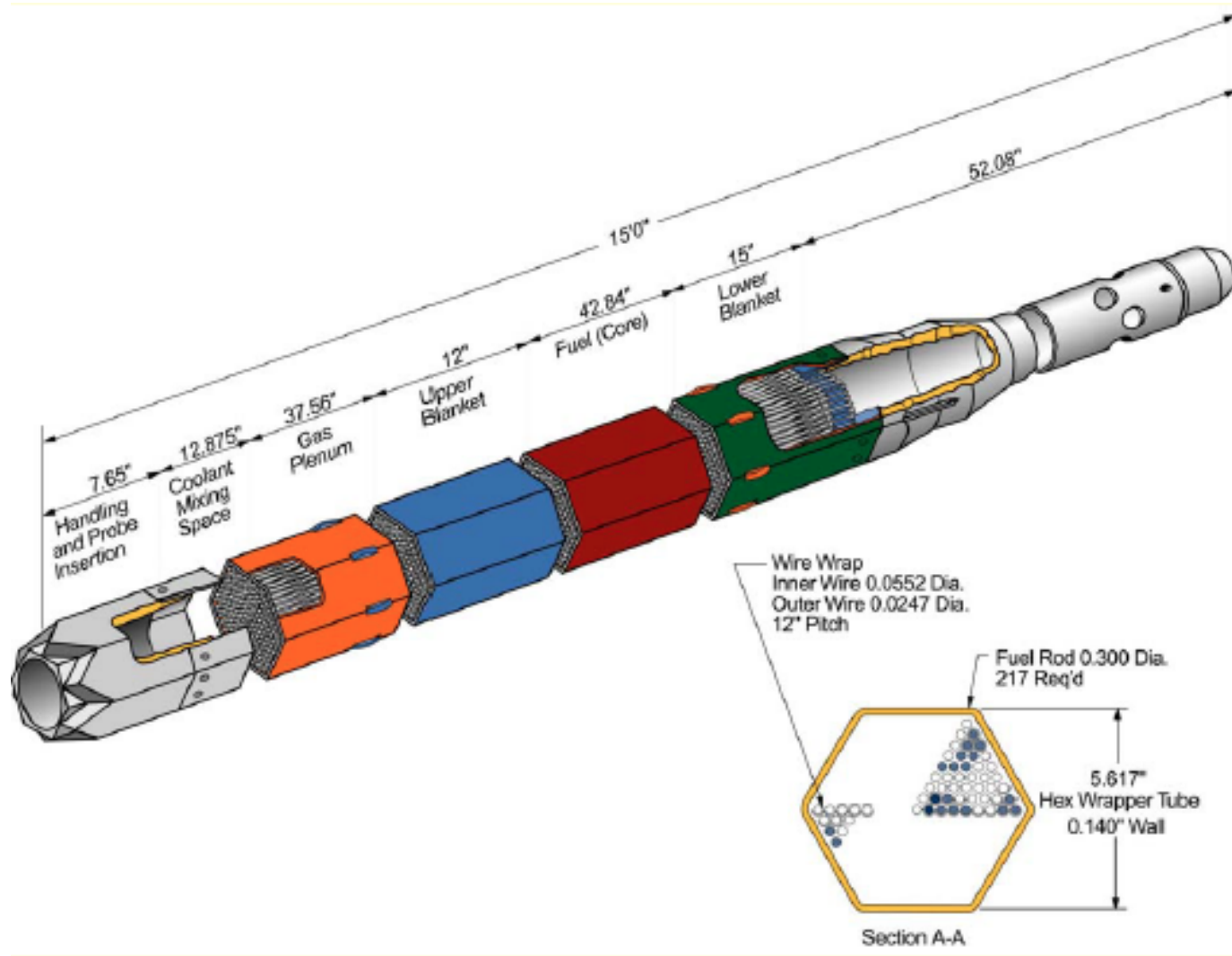
Pressurized Heavy Water Reactor Fuel



CANDU Reactor



Fast Reactor Fuel Assembly



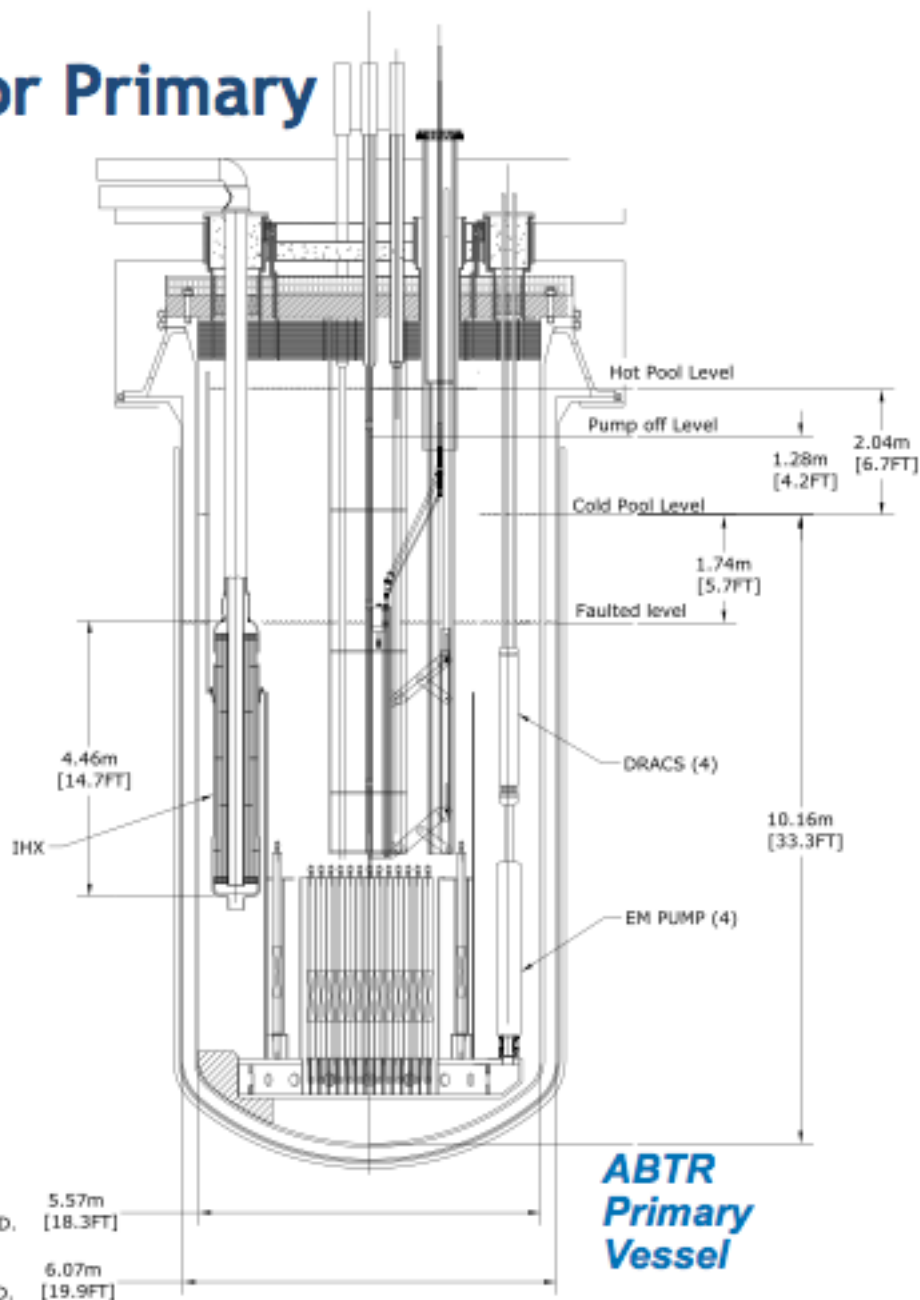
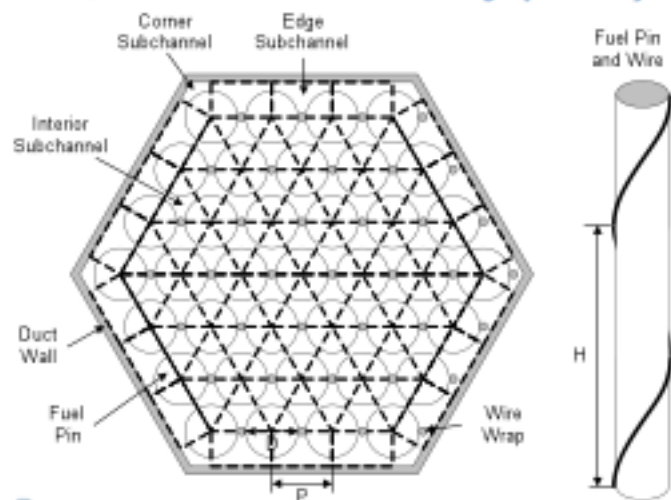
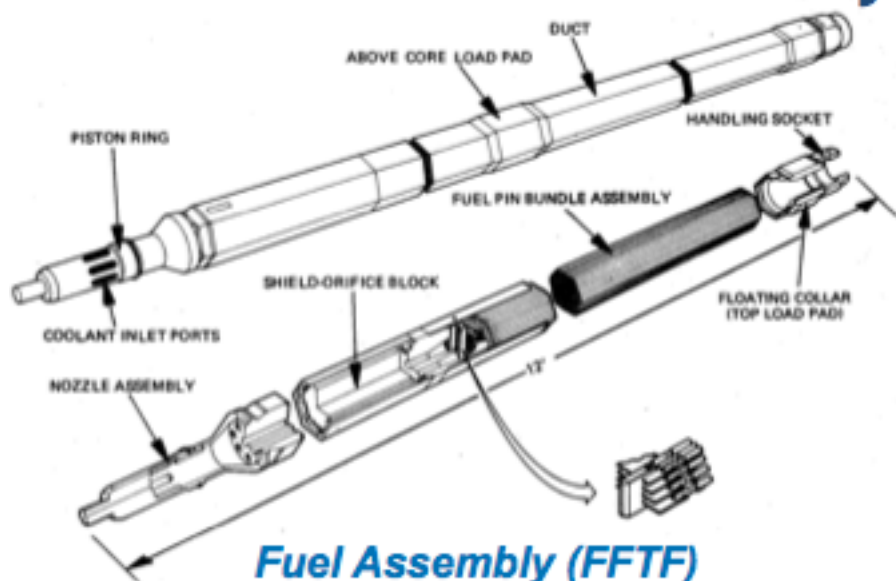
Fast Breeder Reactor Dimensions and Materials

- Dimensions: hexagonal, $H=4-5.5\text{m}$, W (flats)= 10-20 cm; HM height $\sim 2\text{m}$
- Weight: $\sim 60\text{ kgHM}$, $\sim 65\text{ kg MOX}$, $\sim 135\text{ kg}$ hardware (core plus axial blanket)
 - Hardware: Stainless steel
 - Mostly wire wrap for pin spacing
- Fuel element array: 200-300 pins
- Fuel element size: 0.6-0.9 cm OD, $H= 4-5\text{m}$
- Enrichment: 15-30% Pu
- Blanket: All depleted UO_2
 - Fewer, larger diameter elements

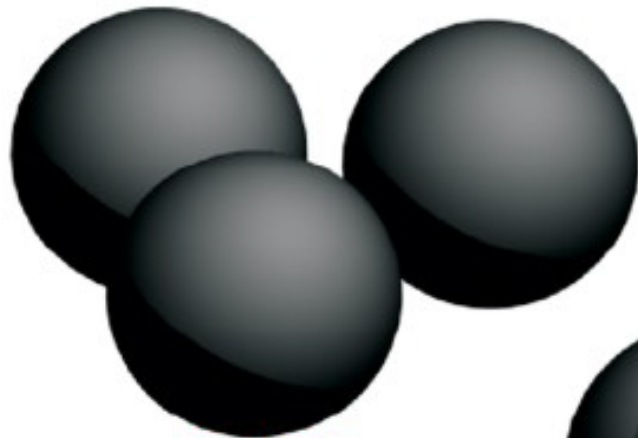
Fast Reactor Fuel Variations

- Designs not settled: considerable variation in number of elements, dimensions, and weights possible
- Reduce breeding/conversion ratio to achieve net destruction of transuranics
 - Eliminate fertile blankets in favor of non-fertile neutron reflectors (e.g., stainless steel)
 - Inert matrix (e.g., ZrO_2) fuel
- Carbide, nitride, or metal fuel instead of oxide

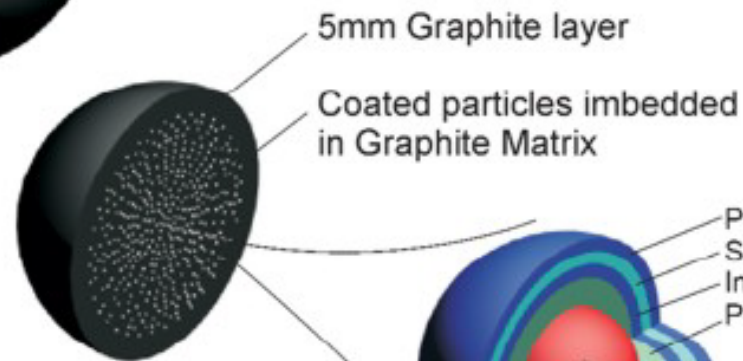
Sodium-Cooled Fast Reactor Primary Vessel and Fuel Assembly



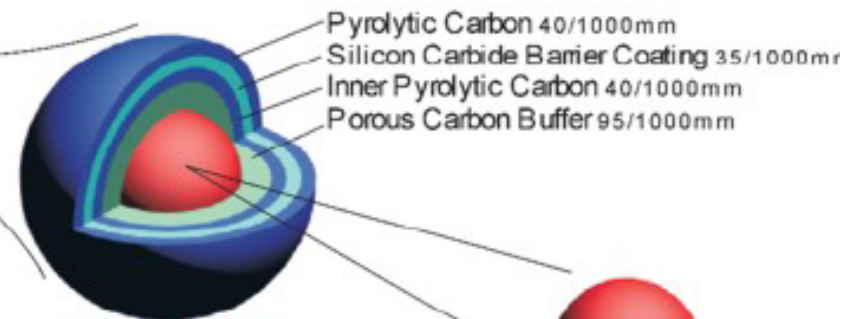
Pebbles!



Dia. 60mm
Fuel Sphere



Section



Dia. 0,92mm

TRISO
Coated Particle

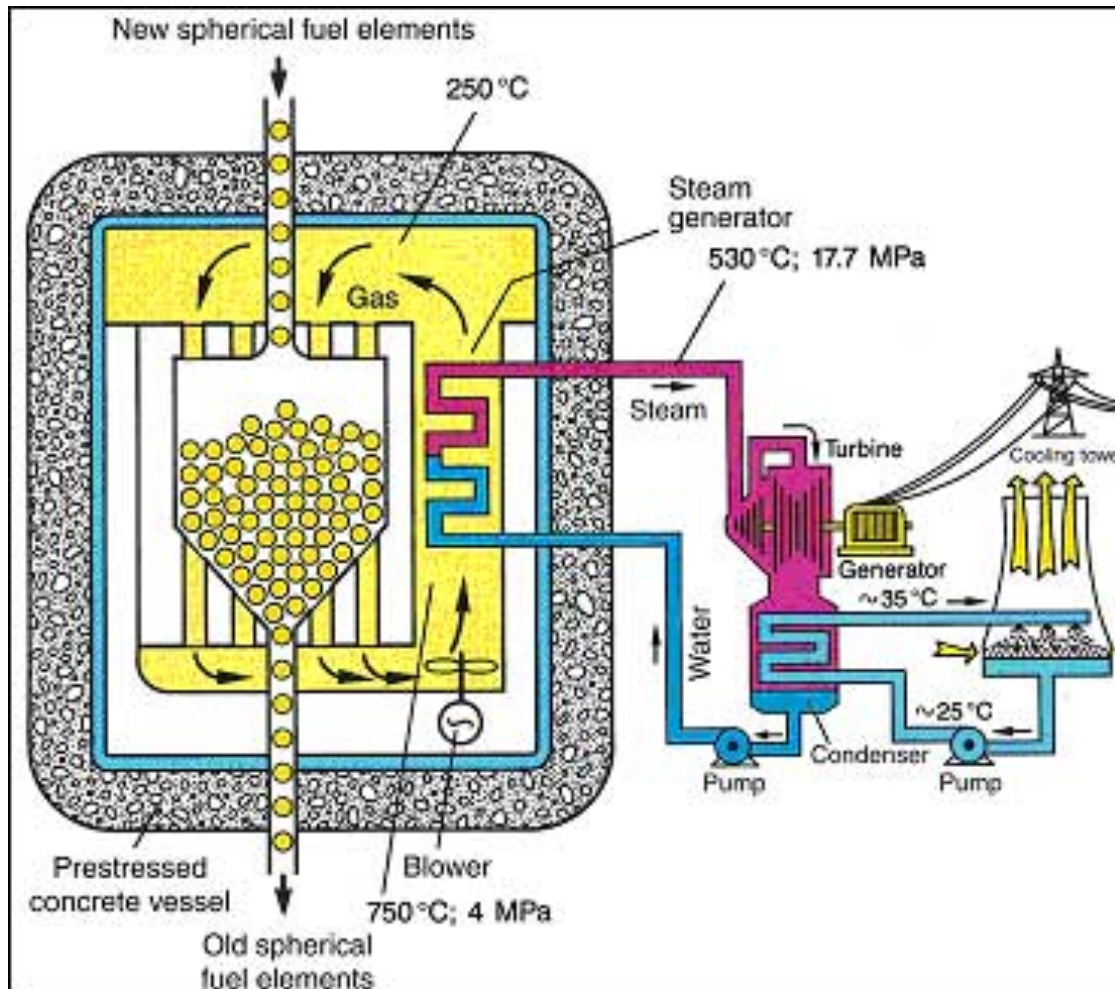


Dia. 0,5mm
Uranium Dioxide
Fuel Kernel

Pebble Bed Reactor Fuel

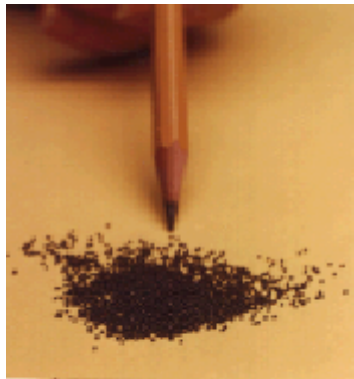
- Dimensions: Spherical, $D = 6.0$ cm
- Weight: 9 g U, 10 g UO_2
 - “Hardware” 194 g C (mostly graphite), ~6 g SiC
- ~360,000 pebbles for 400 MW(t) reactor
- Fuel element array: random pile
- Fuel element size:
 - 900 μm TRISO particle
 - ~15,000 particles per pebble
- Enrichment: 7-10%

Pebble Bed Reactors



- Several types, PBMR well known
- Power controlled by adding or removing helium coolant—no control rods
- Pebble recycling maintains constant reactivity and achieves very high fuel burnup

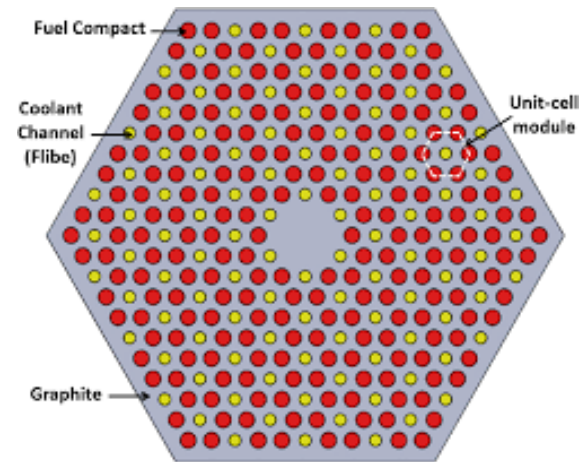
TRISO Particles as Fuel Compacts for Prismatic Fuel



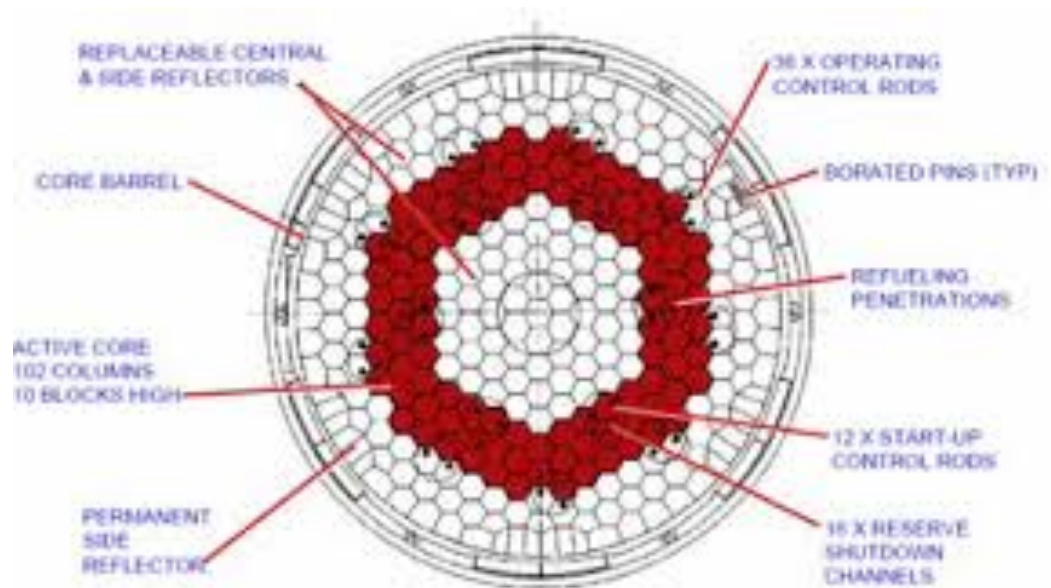
PARTICLES



COMPACTS



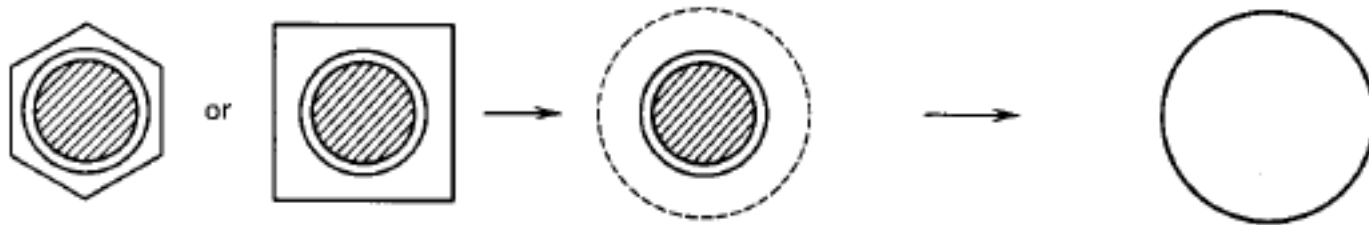
FUEL ELEMENTS



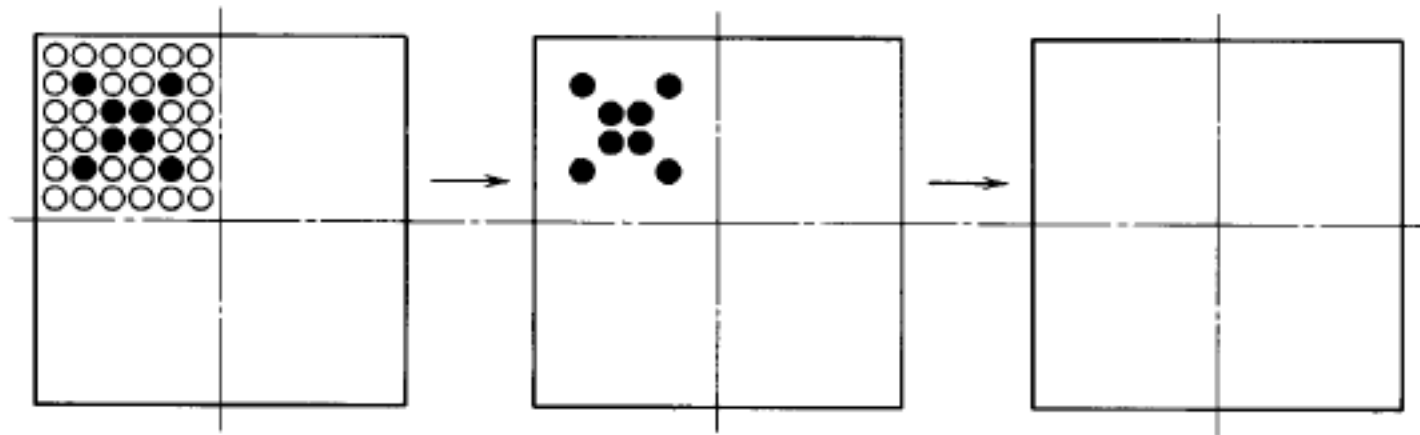
HTGR Prismatic Fuel

- Dimensions: hexagonal, $H=0.8\text{m}$, 0.36m (flats)
- Weight: 5-7 kgU, 5.5-7.5 kg UO_2
 - Hardware 126 kg C (mostly graphite), 4 kg SiC
- ~1000 blocks for 600 MW(t) reactor
- Fuel element array: 210 on a triangular pitch
 - 108 Coolant channels
- Fuel element size: 1.3 cm OD, $H=0.8\text{m}$
 - Contains 14-15 “compacts” with 350-500 μm TRISO particles
- Enrichment: 8-20%
- May have separate B_4C burnable poison rods²⁸

Simplifications

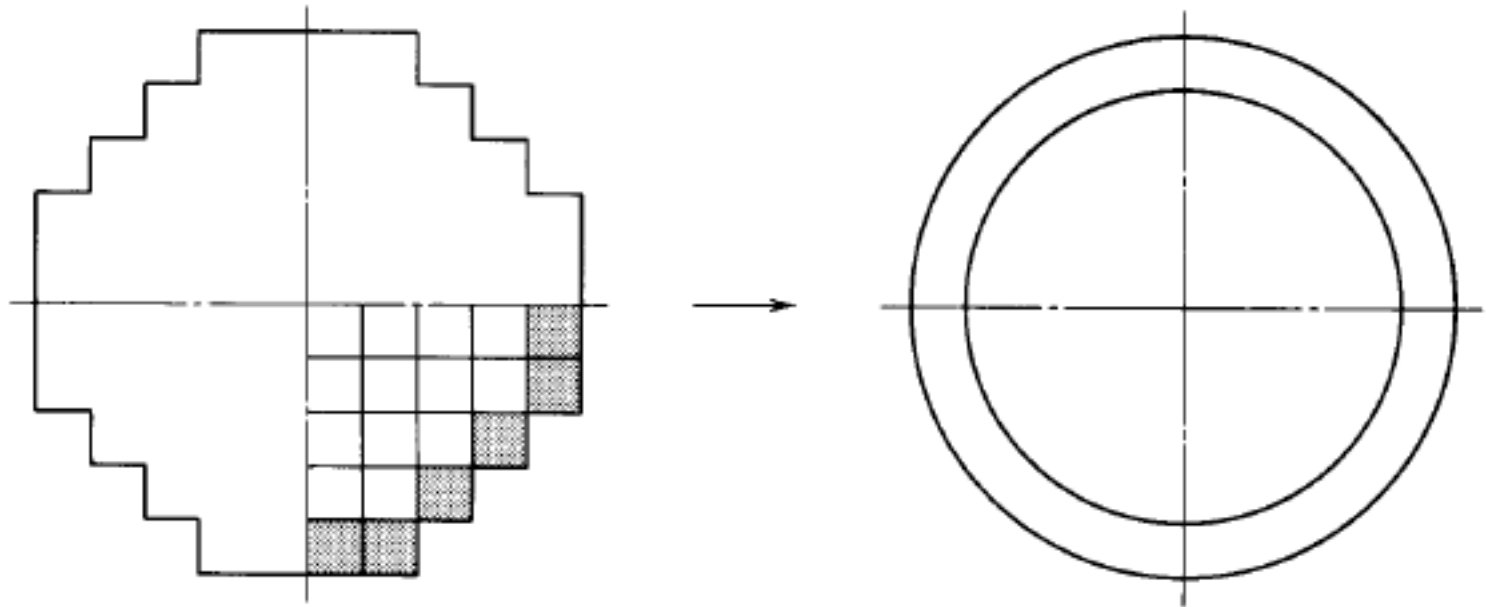


(a) Fuel-cell homogenization



(b) Fuel-assembly homogenization

Simplifications

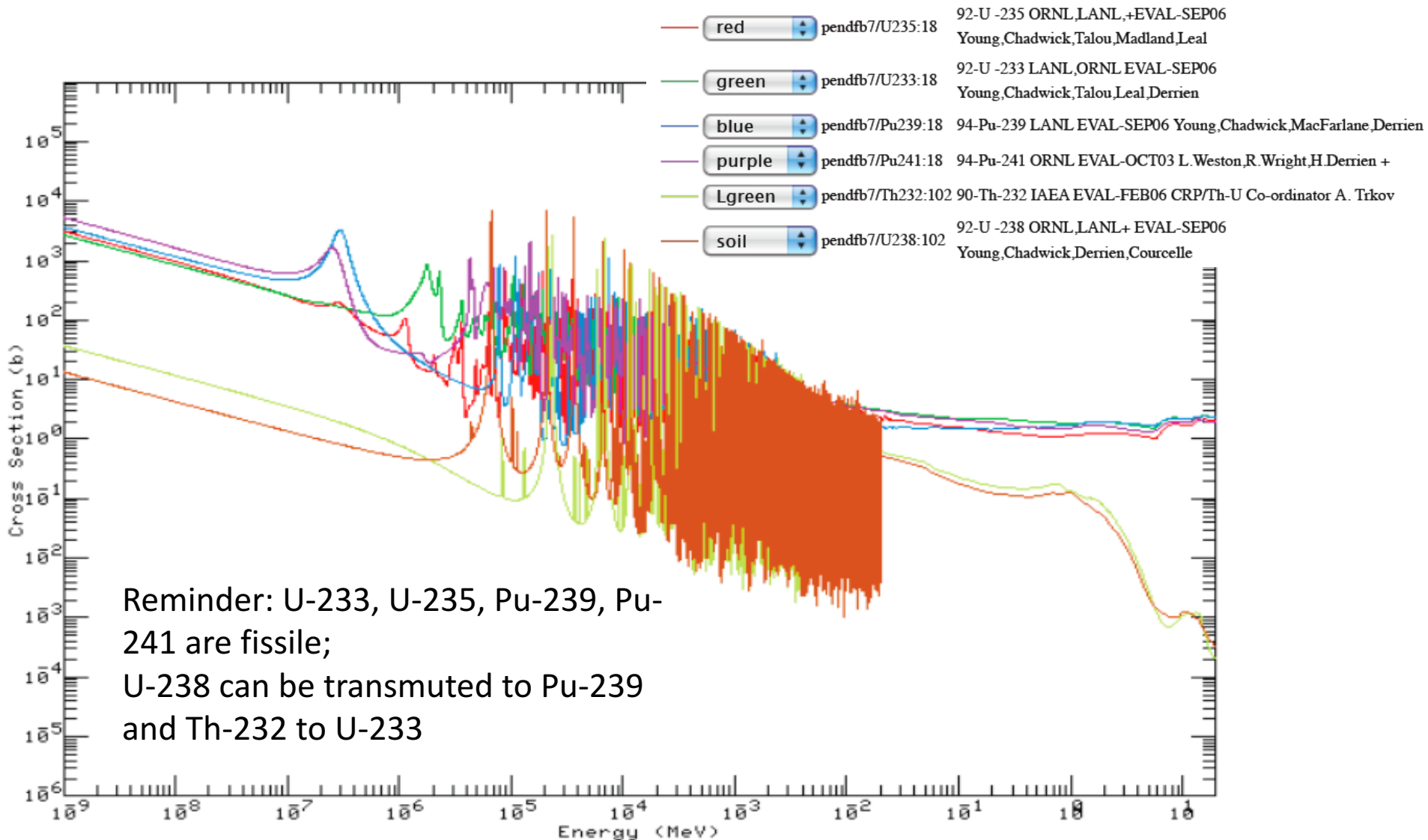


(c) Core homogenization

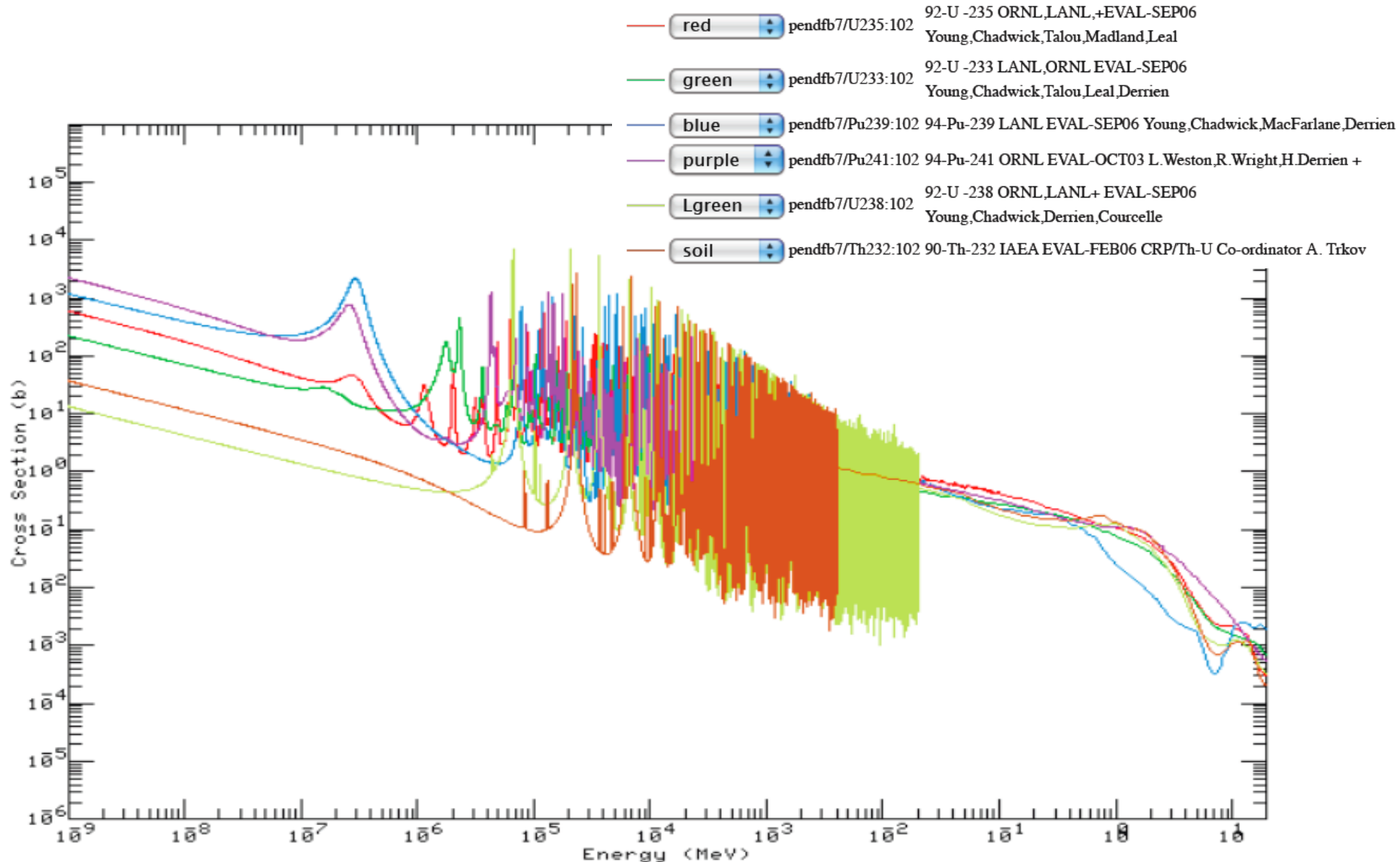
Back to the Board...

Fission Cross Sections for U-233, U-235, Pu-239, Pu-241 vs. Capture Cross Sections for U-238 and Th-232

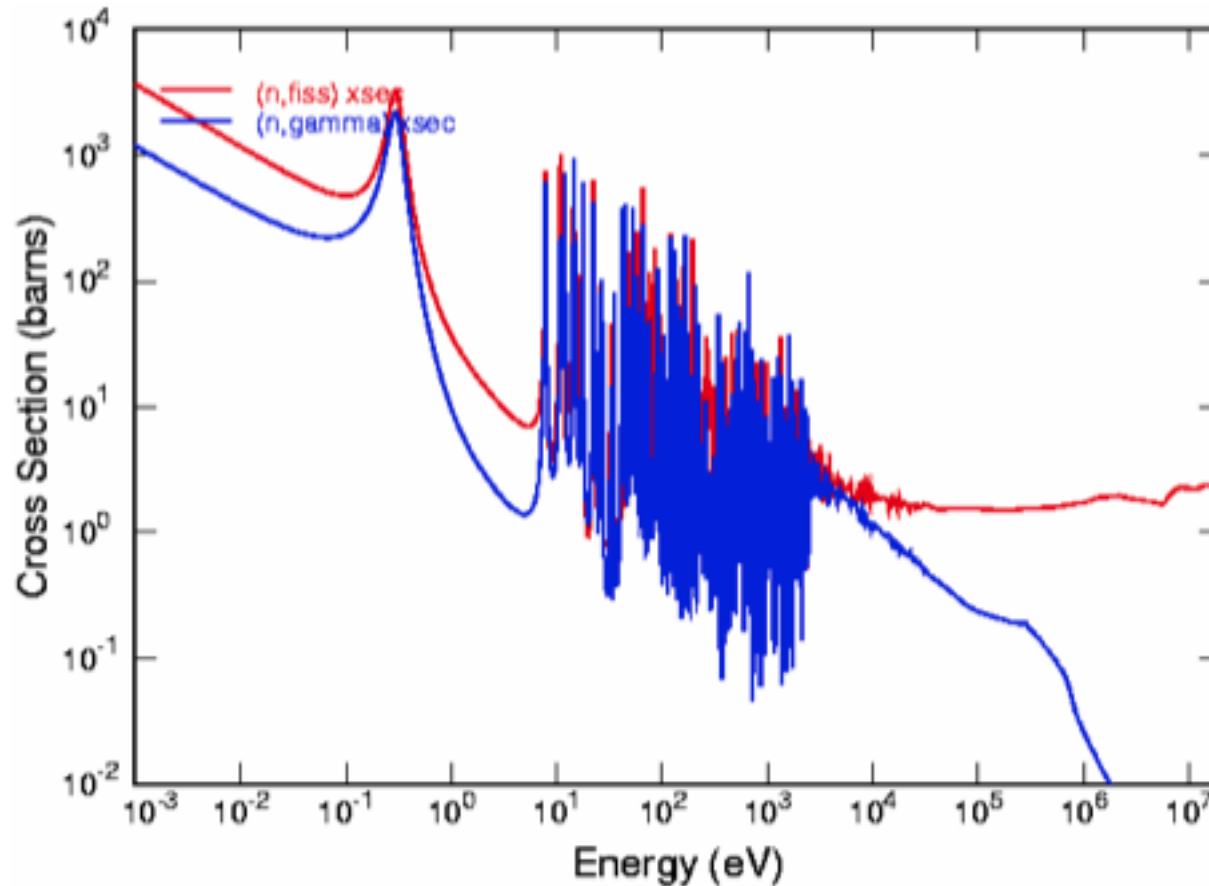
<http://atom.kaeri.re.kr/>



Capture Cross Sections for U-235, U-233, Pu-239, Pu-241 vs. Capture Cross Sections for U-238 and Th-232

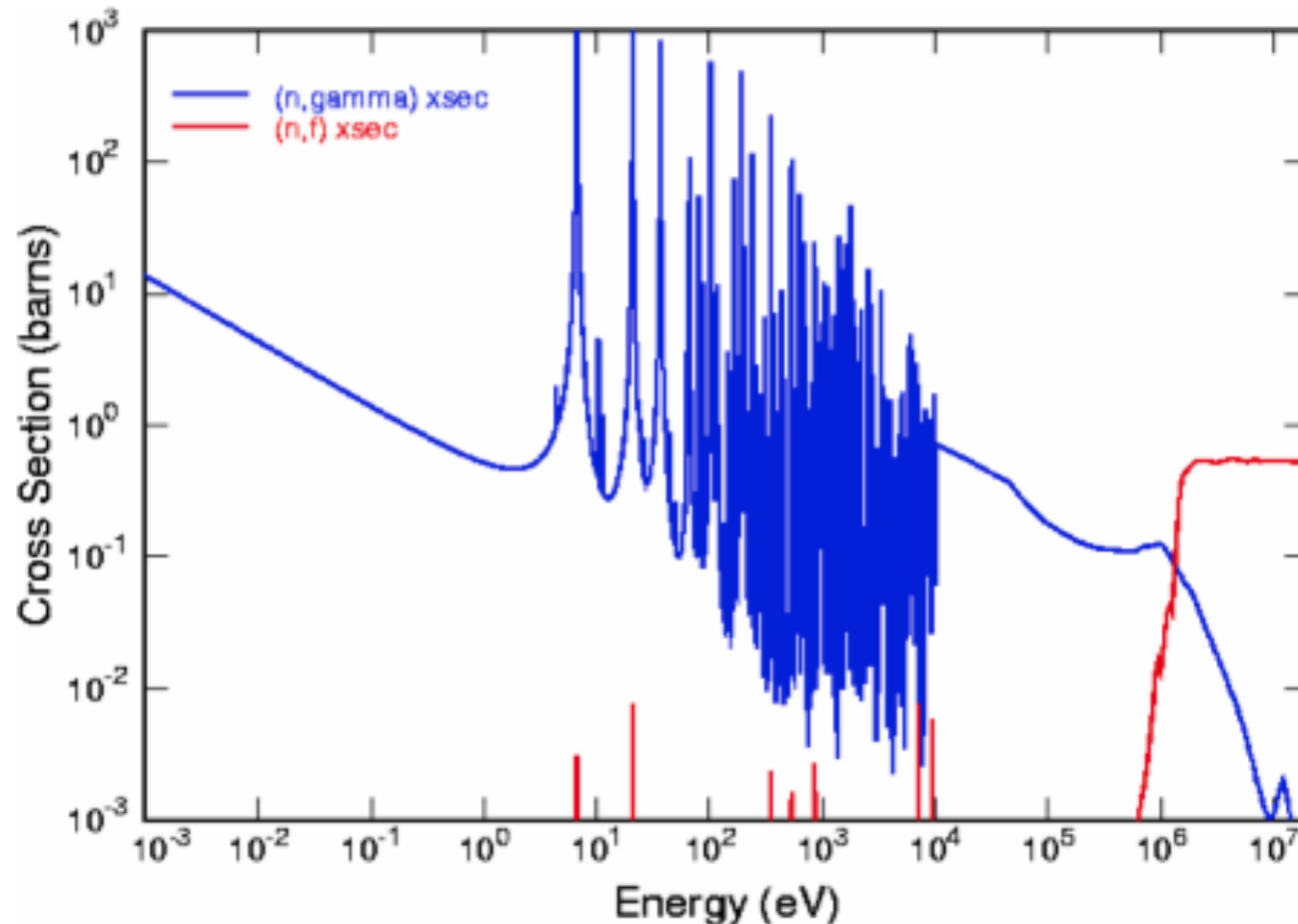


Spectral Variations of Neutron Cross Sections: Pu-239



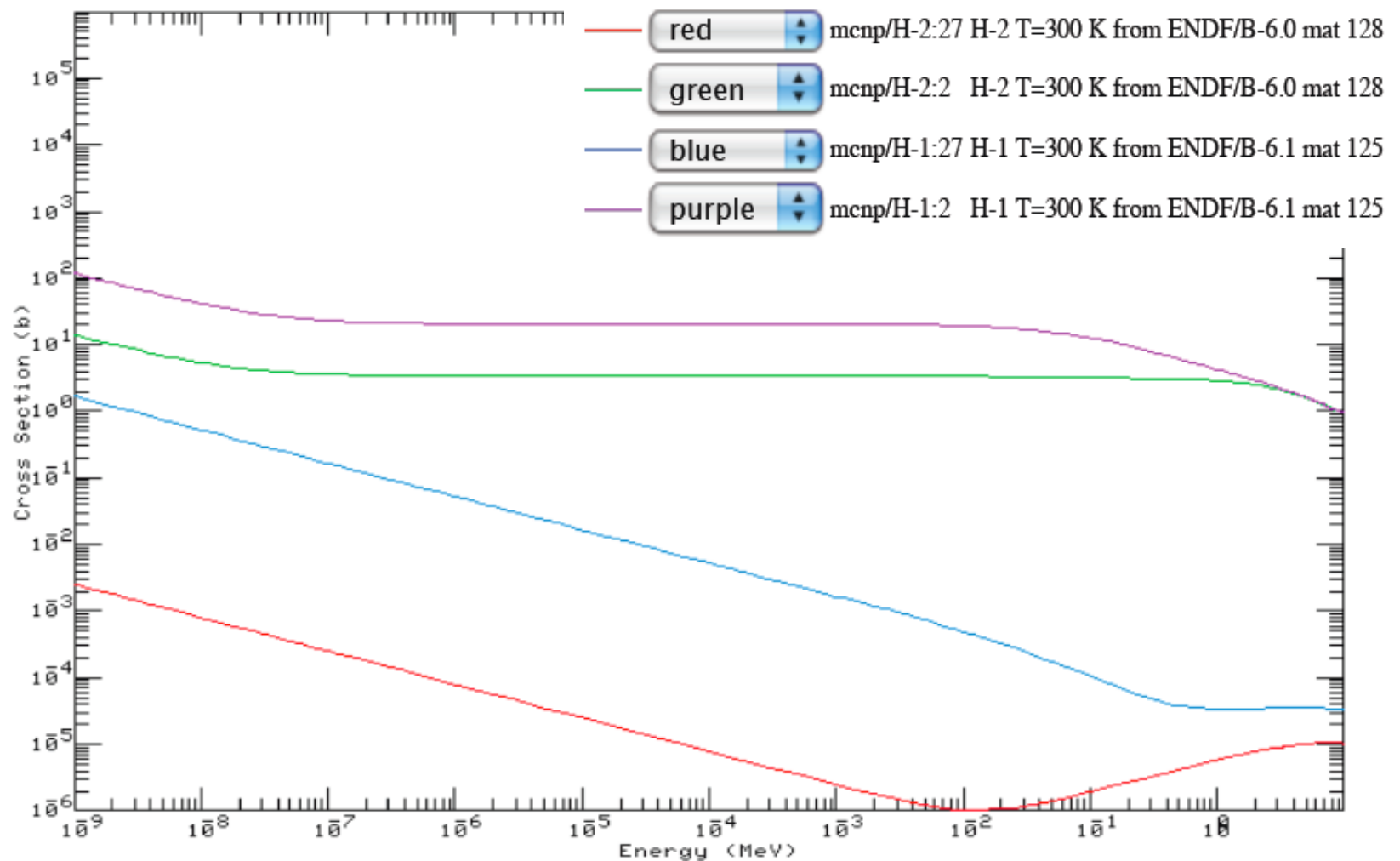
- Fission and capture cross sections $> 100 \times$ larger in thermal neutron energy region
- Sharp decrease in capture cross sections in at high neutron energy

Spectral Variations of Neutron Cross Sections: U-238

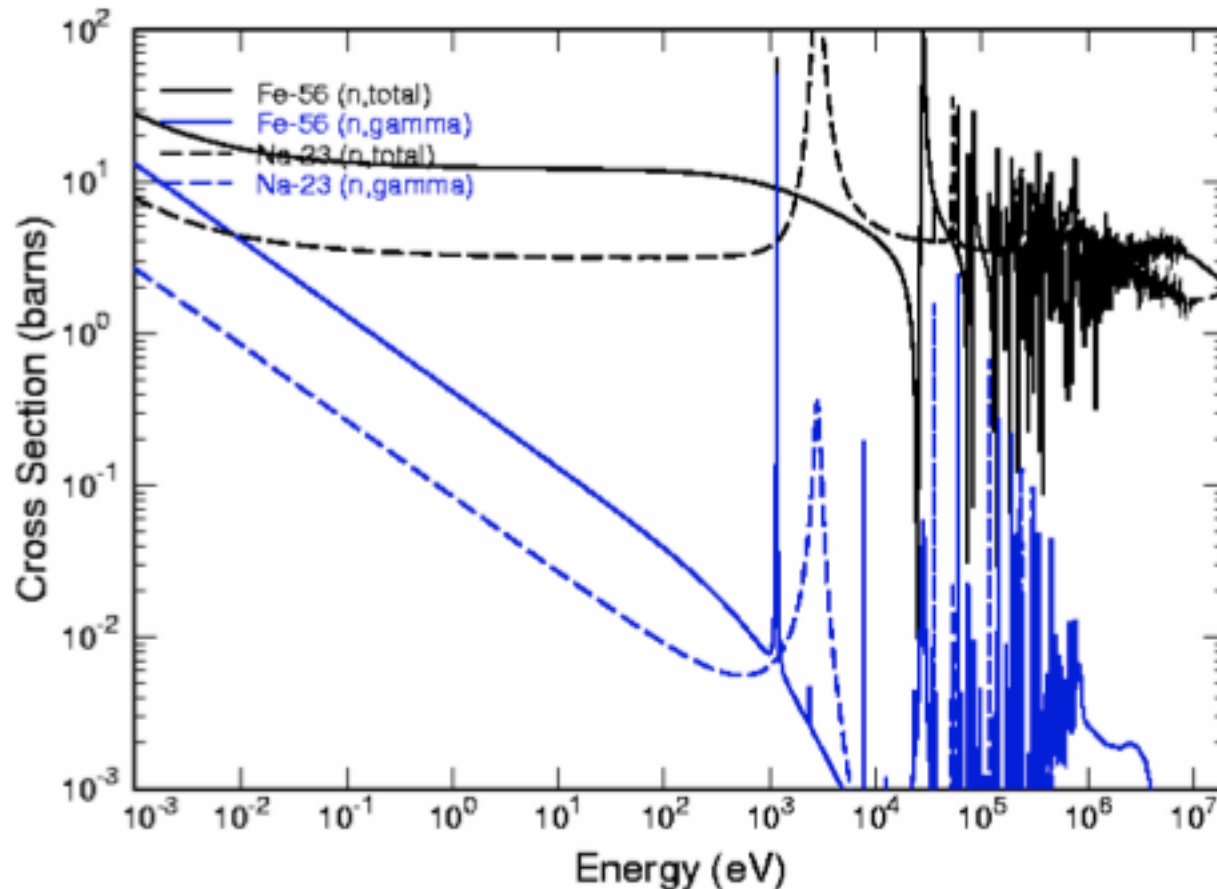


- Fission threshold at $\sim 1\text{MeV}$
- Unresolved resonance region begins at $\sim 10\text{ keV}$

Elastic scattering and capture cross sections for H and D

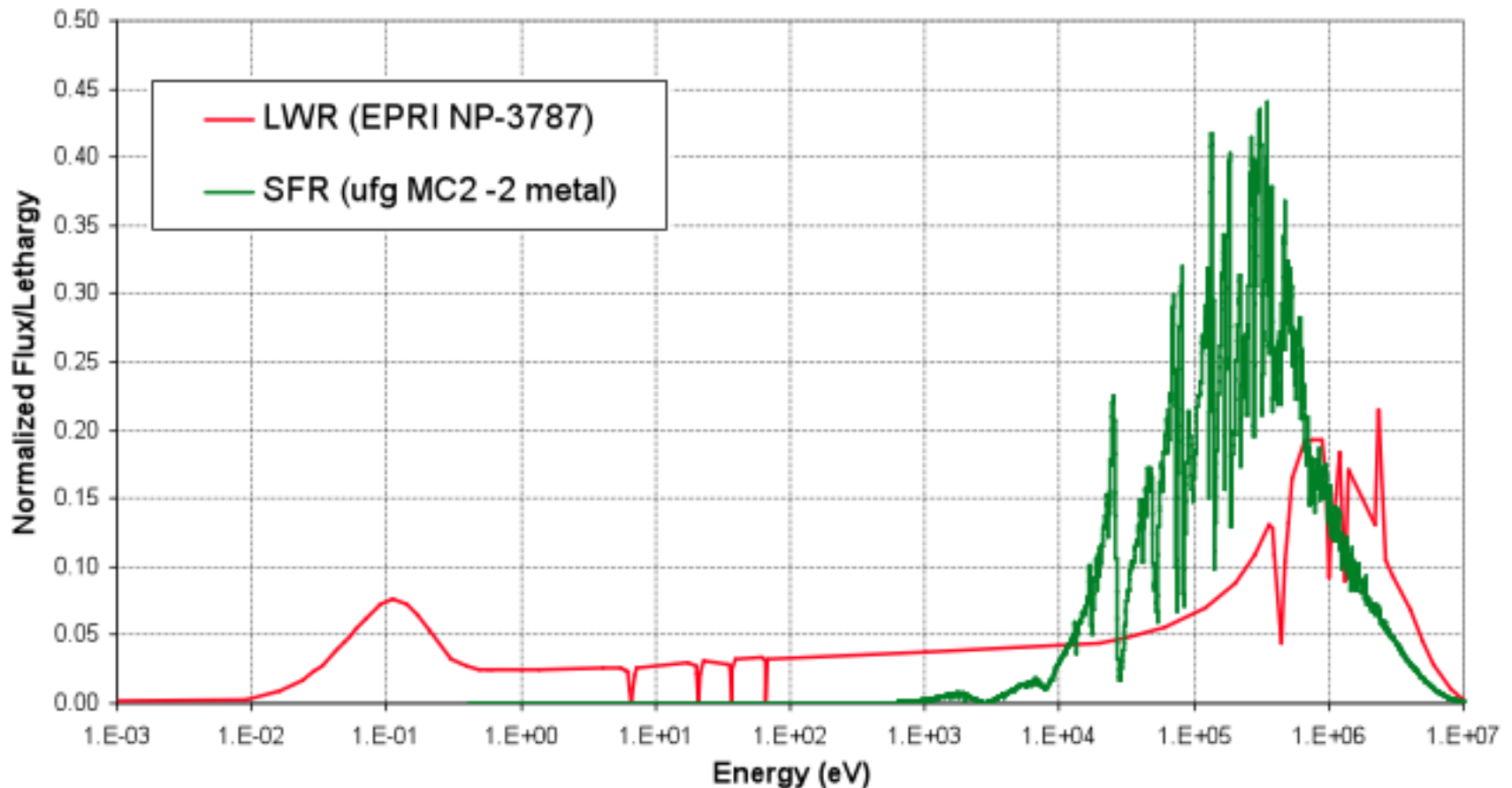


Spectral Variations of Neutron Cross Sections: Na and Fe



- Capture cross section much smaller in the fast region

Comparison of Thermal and Fast Reactor Spectra



- In LWRs most fissions occur in the 0.1 eV thermal “peak”
- In SFRs moderation is avoided – no thermal neutrons