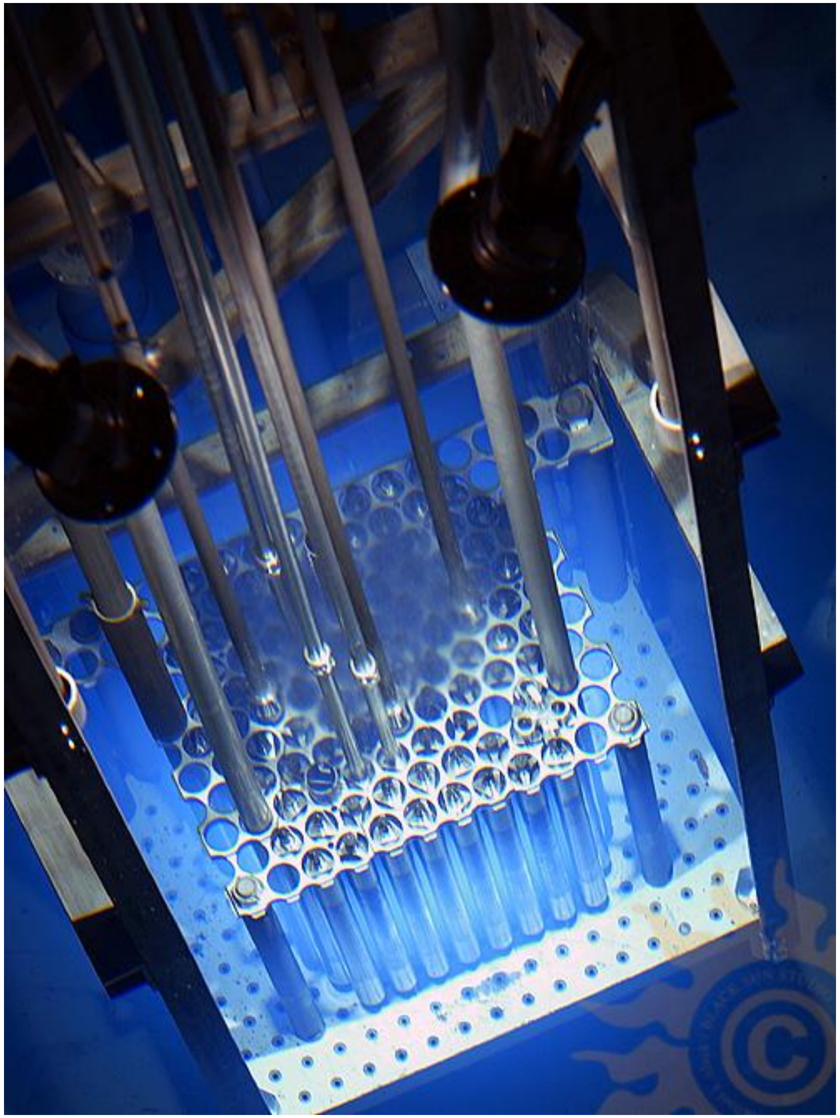


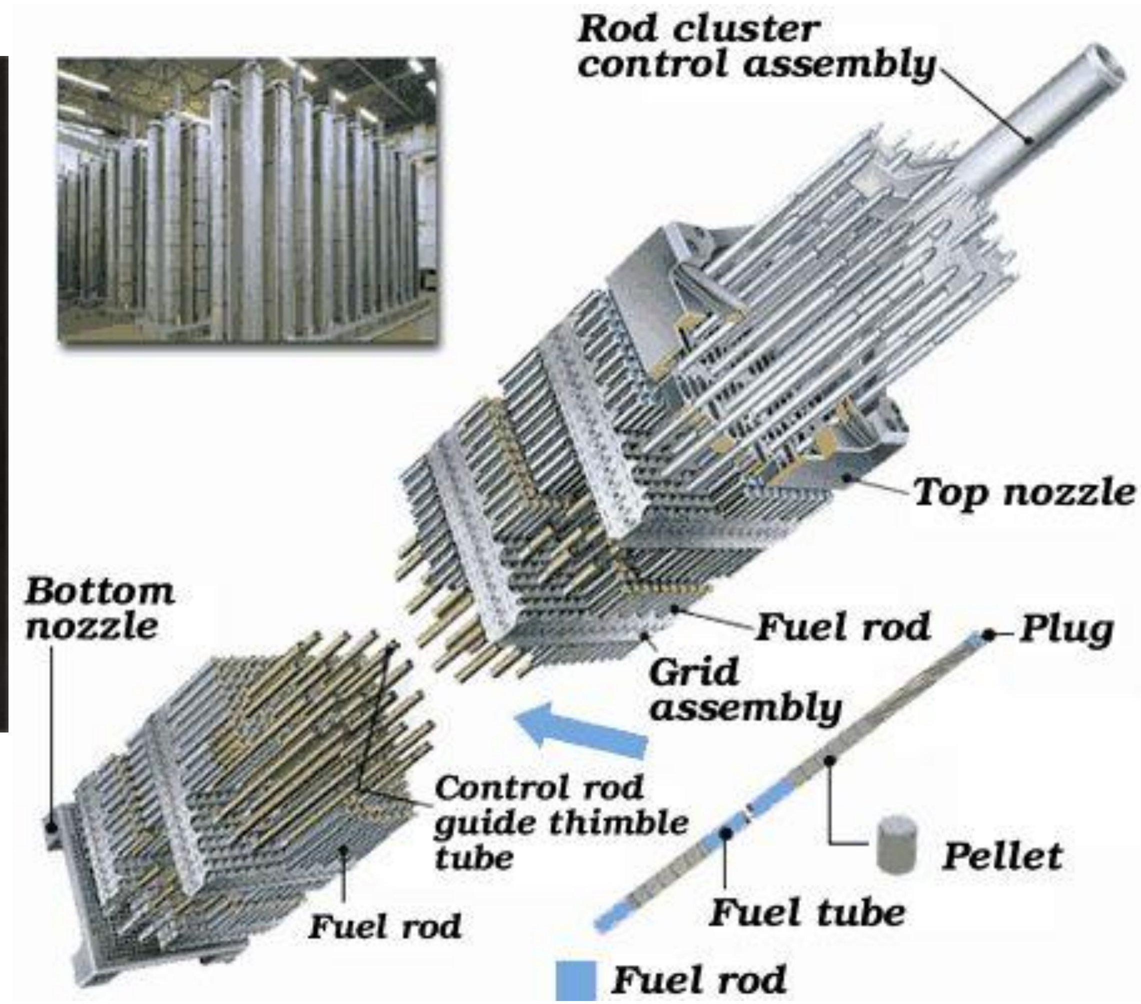
Nuclear Reactor Context

Rachel Slaybaugh
(derived from Vujic notes)

NE255

September 20, 2016

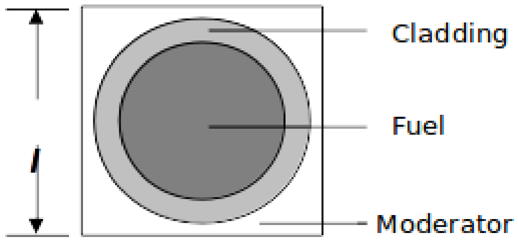
Nuclear Fuel Pellet, PWR Assembly



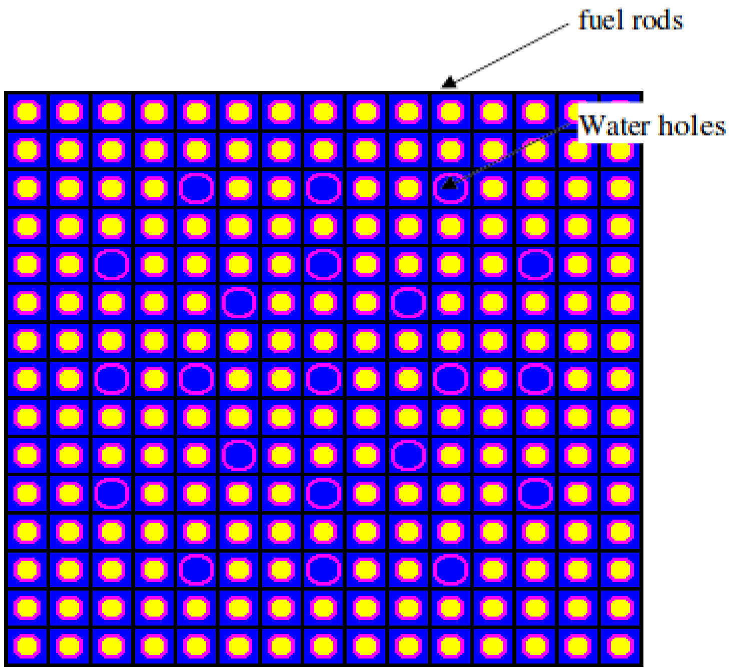
PWR Fuel Dimensions and Materials

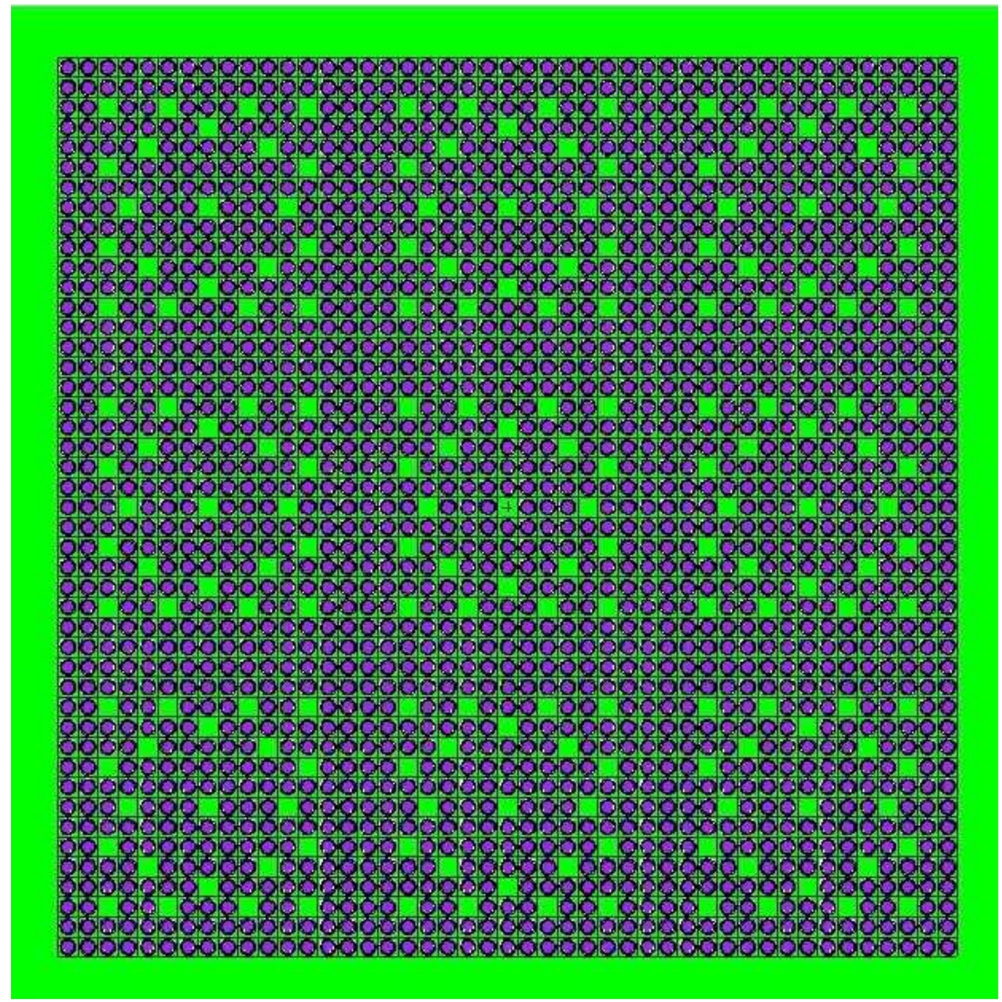
- Dimensions: square, H=4.1m, 21cm x 21 cm
- Weight: 460 kgU, 520 kg UO_2, 135 kg hardware
  - Hardware mostly Zircaloy (Zr with Sn, Fe, Cr)
  - Grid spacers: Zircaloy, Inconel, stainless steel
  - End pieces: Stainless steel, Inconel
- Fuel element array: 14 x 14 to 17 x 17
- Fuel element size: 1 cm OD, H=3.9m
- Enrichment: 3-5%
- May have separate burnable poison rods

PWR Assembly Geometrical Variations

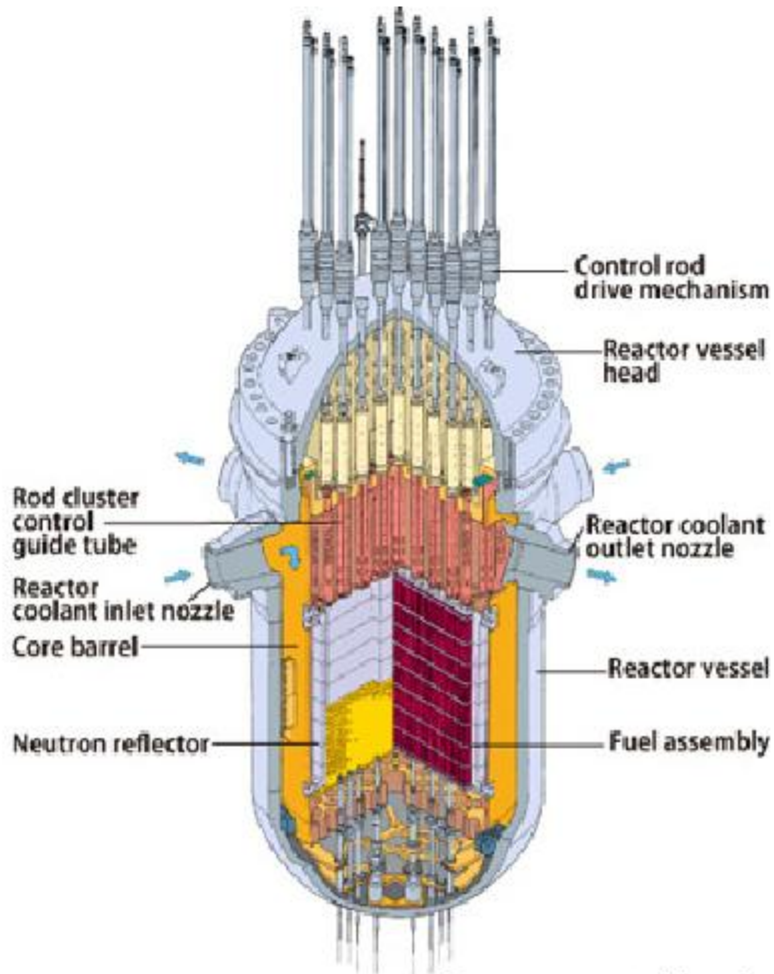


Cross-sectional view of single fuel cell.

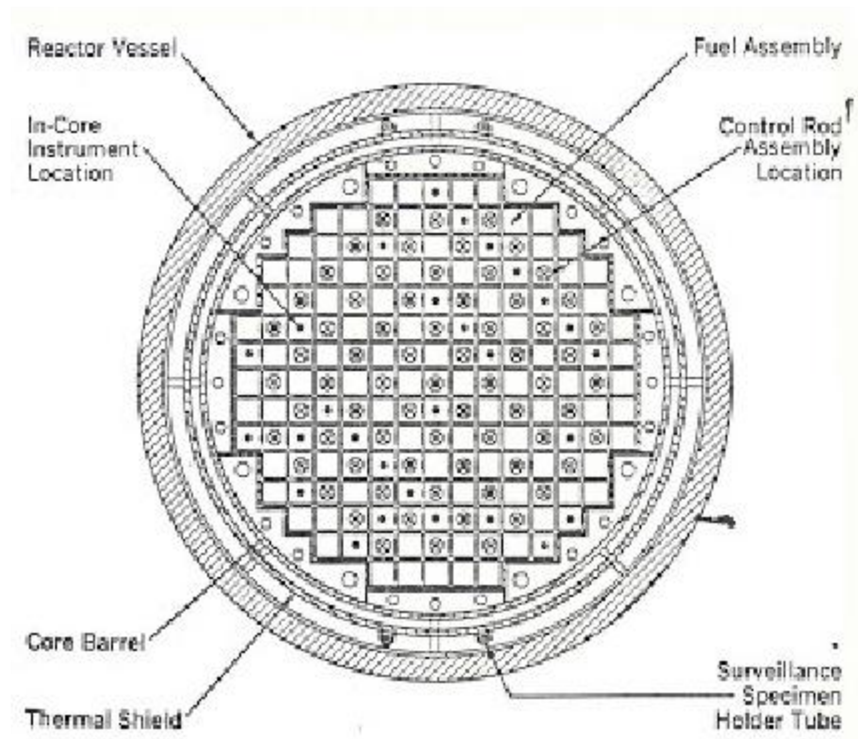




Typical PWR Pressurized Reactor Vessel



Source: www.mhi.co.jp



BWR Fuel Assemblies

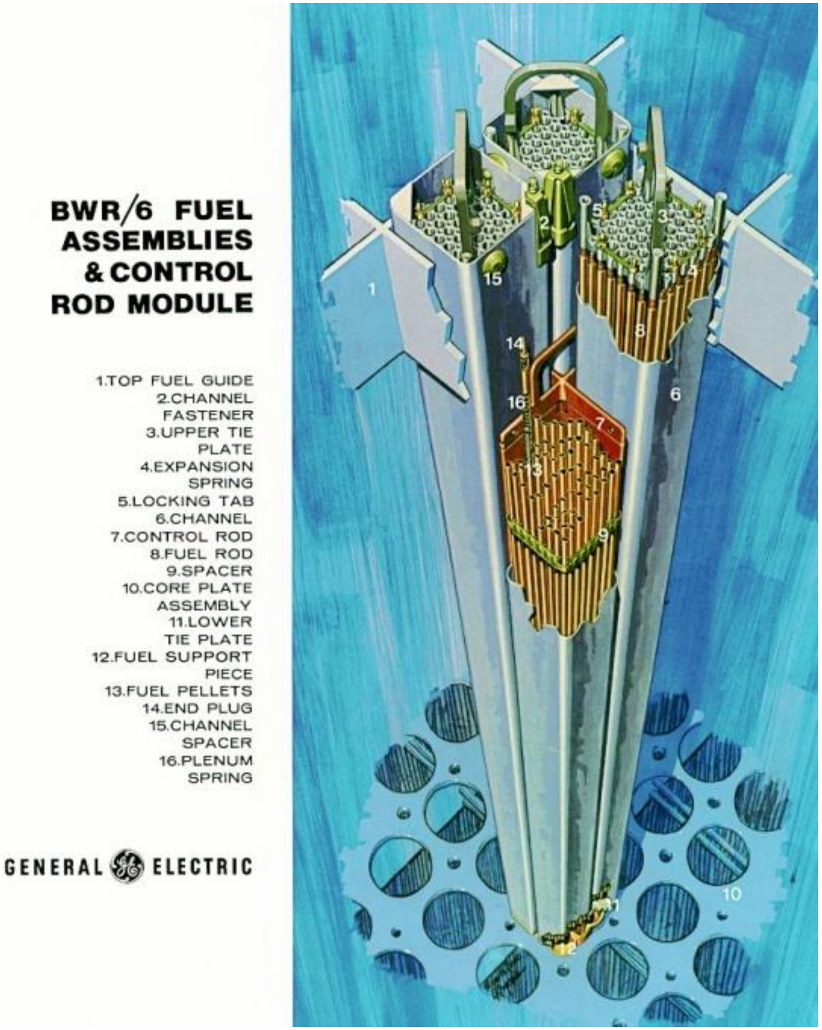
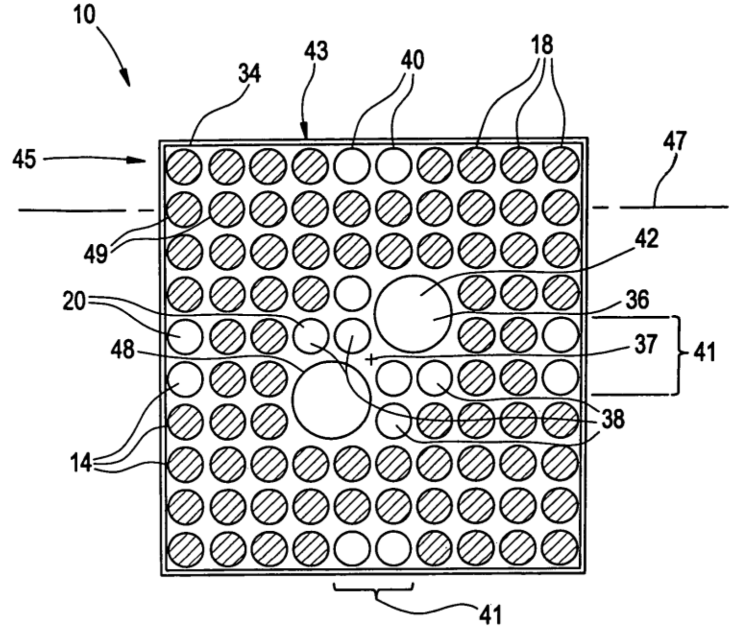


FIG. 2



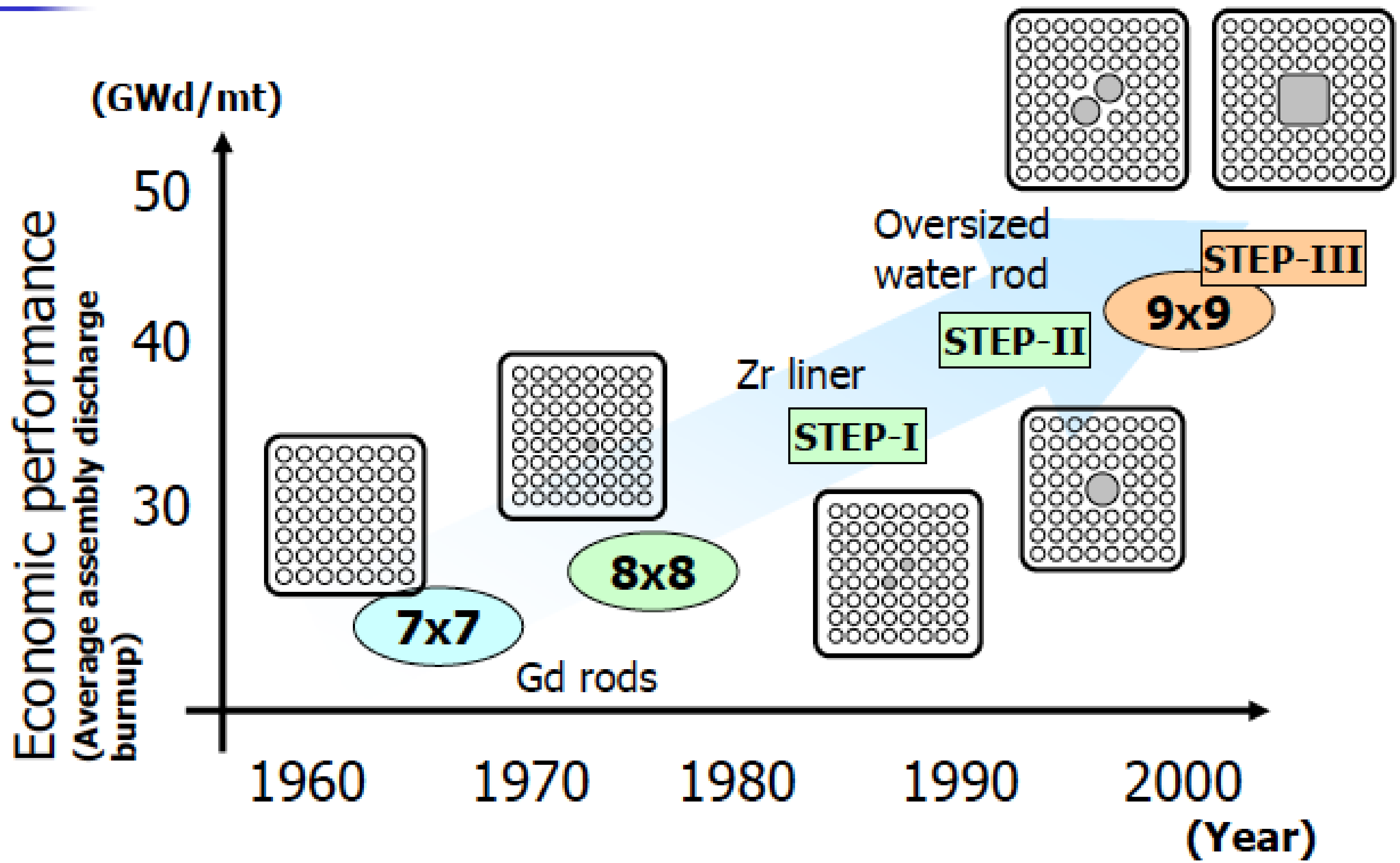
Denotes Full - Length Fuel Rods

Denotes Part - Length Fuel Rods

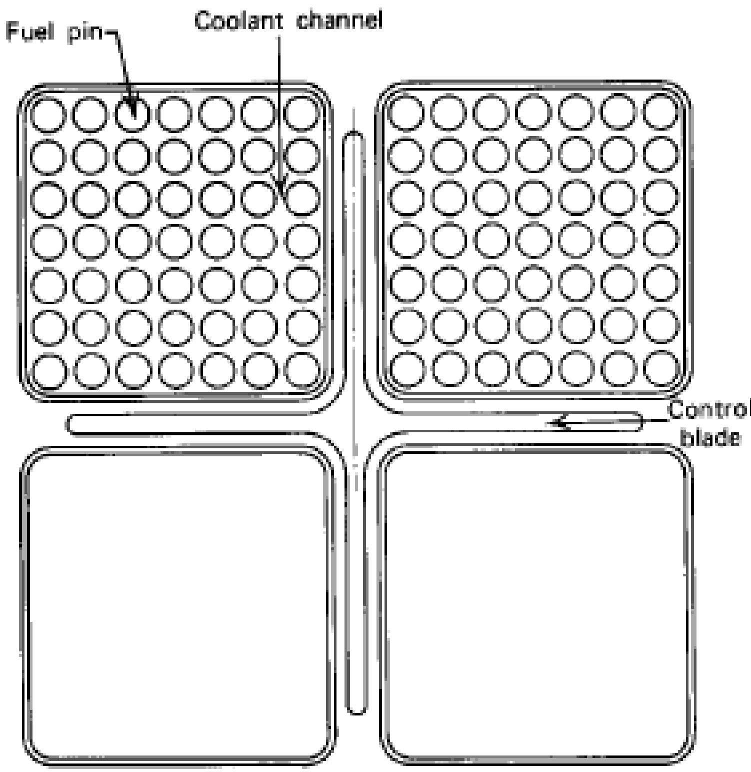
BWR Fuel Dimensions and Materials

- 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

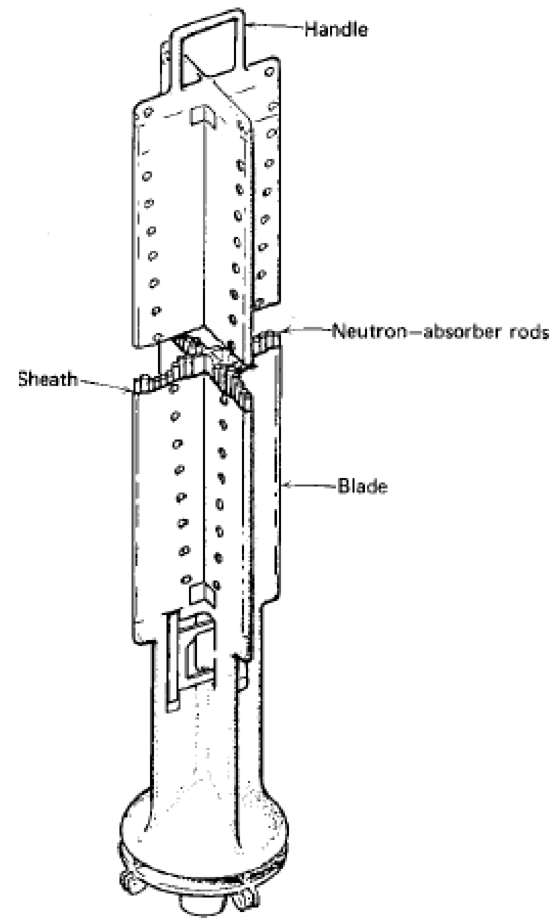
History of GE BWR Fuel Assembly Designs



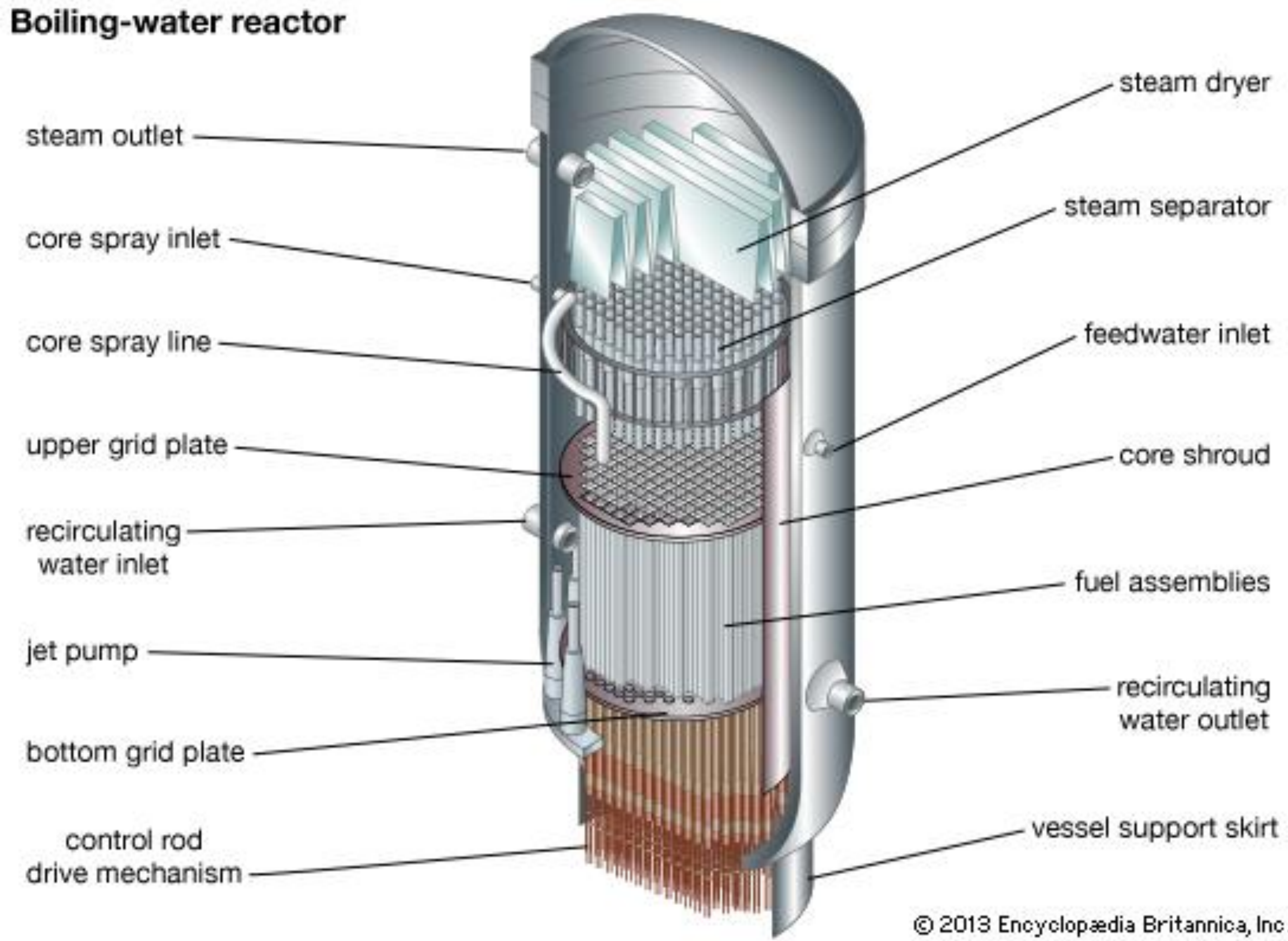
Four BWR Assemblies and A Cruciform Control Blade



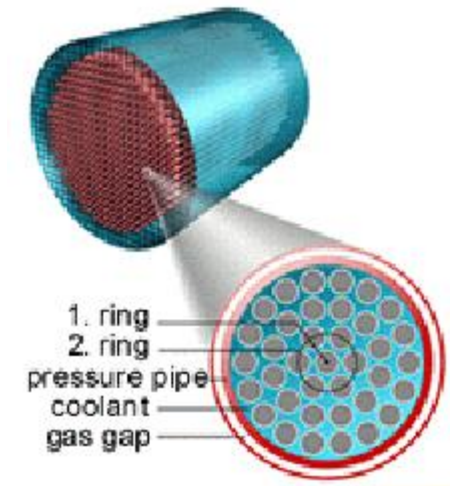
BWR assemblies

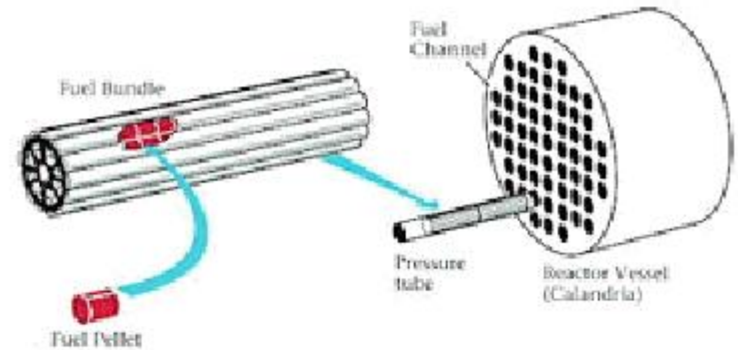


Boiling Water Reactor

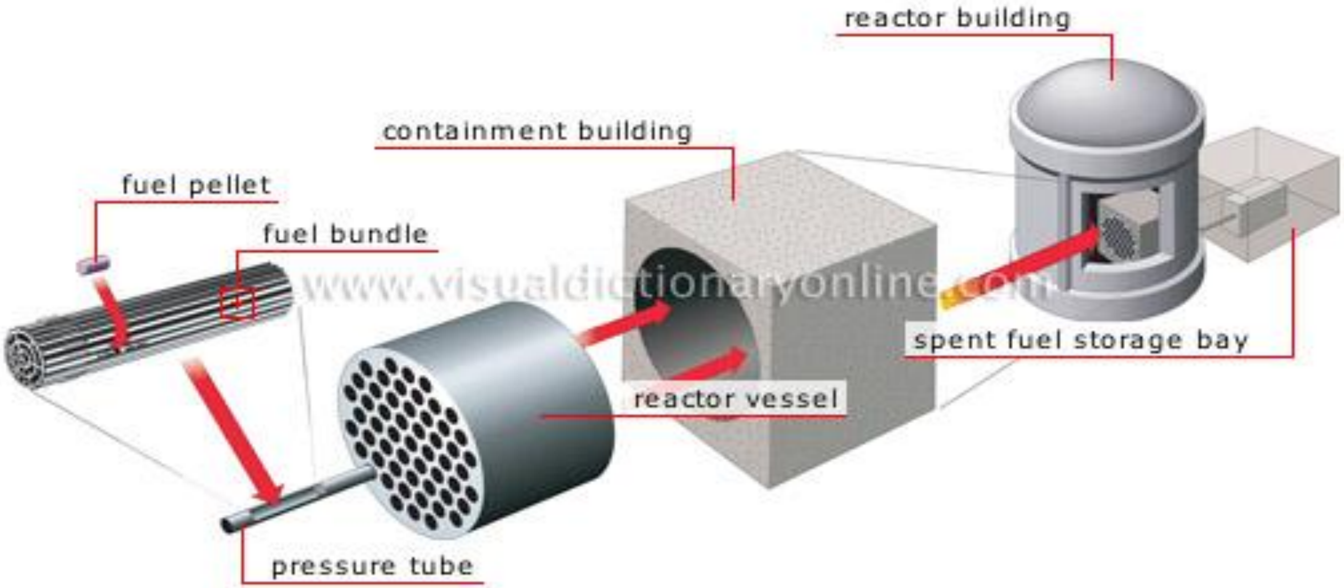


Pressurized Heavy Water Reactor Fuel

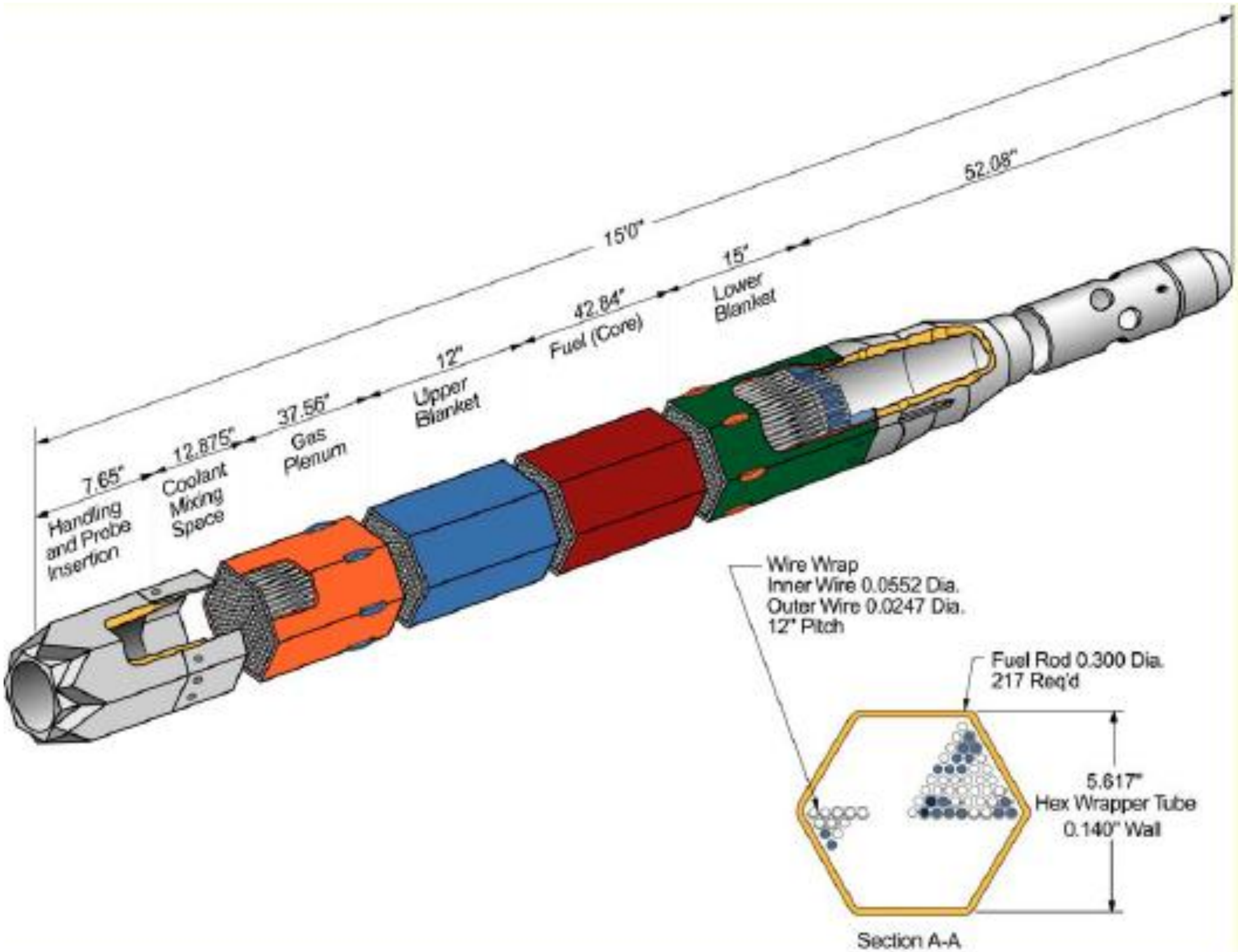




CANDU Reactor



Fast Reactor Fuel Assembly



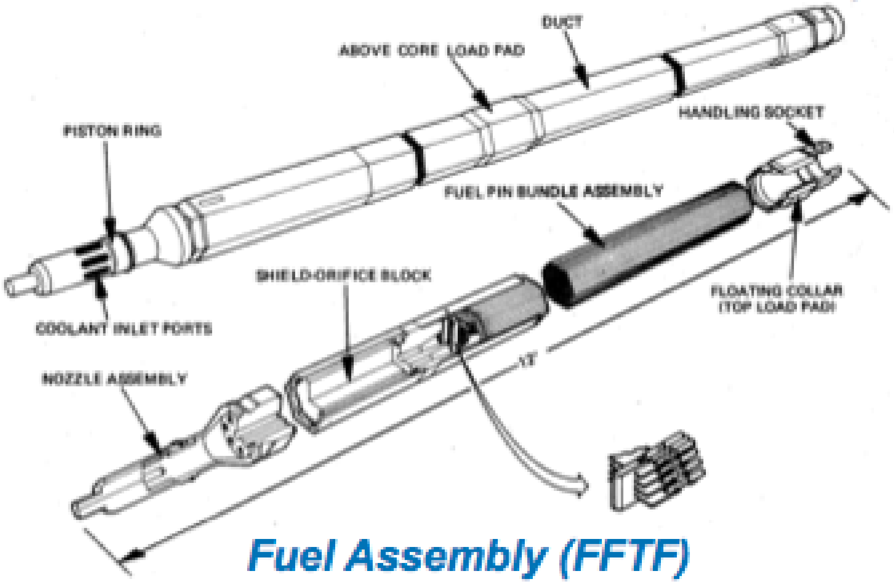
Fast Breeder Reactor Dimensions and Materials

- Dimensions: hexagonal, H=4-5.5m, W (flats)= 10-20 cm; HM height ~2m
- Weight: ~60 kgHM, ~65 kg MOX, ~135 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= 4-5m
- Enrichment: 15-30% Pu
- Blanket: All depleted UO_2
  - Fewer, larger diameter elements

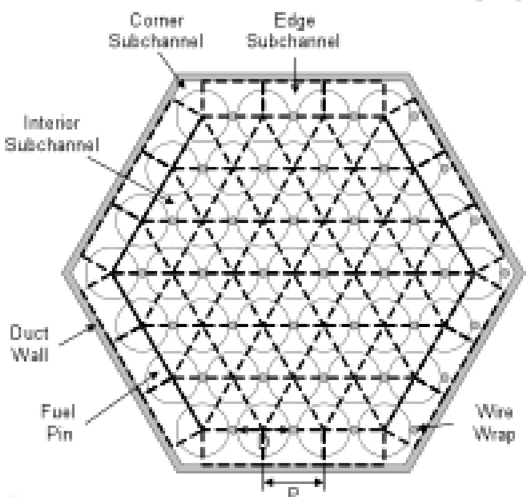
Fast Reactor Fuel Variations

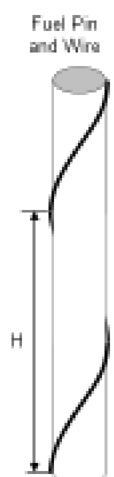
- Designs not settled: considerable variation in number of elements, dimensions, and weights possible
- Reduce breeding/conversion ratio to achieve net destruction of transuranics
  - Eliminate fertile blankets in favor of non-fertile neutron reflectors (e.g., stainless steel)
  - Inert matrix (e.g.,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

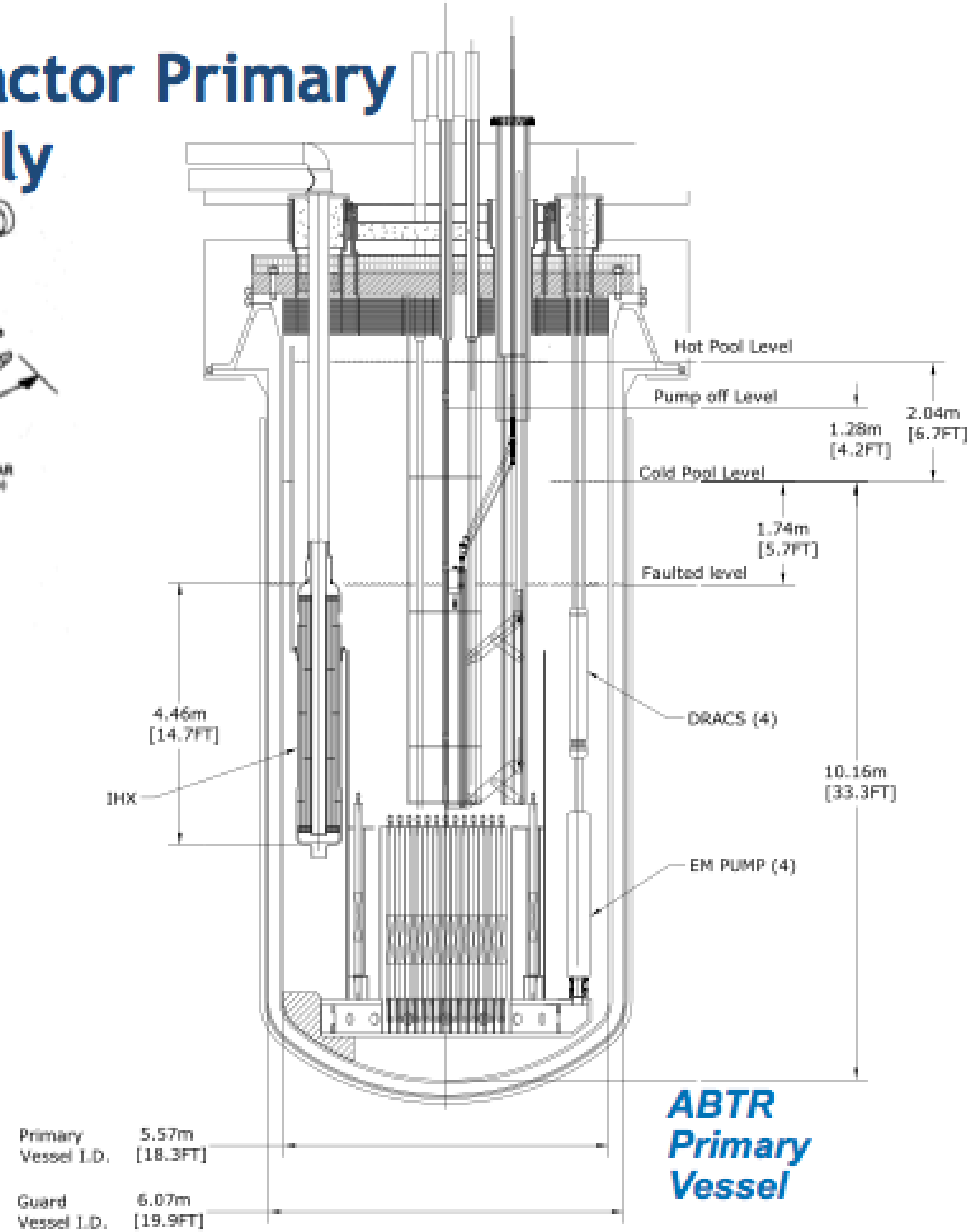
Sodium-Cooled Fast Reactor Primary Vessel and Fuel Assembly



Fuel Assembly (FFTF)

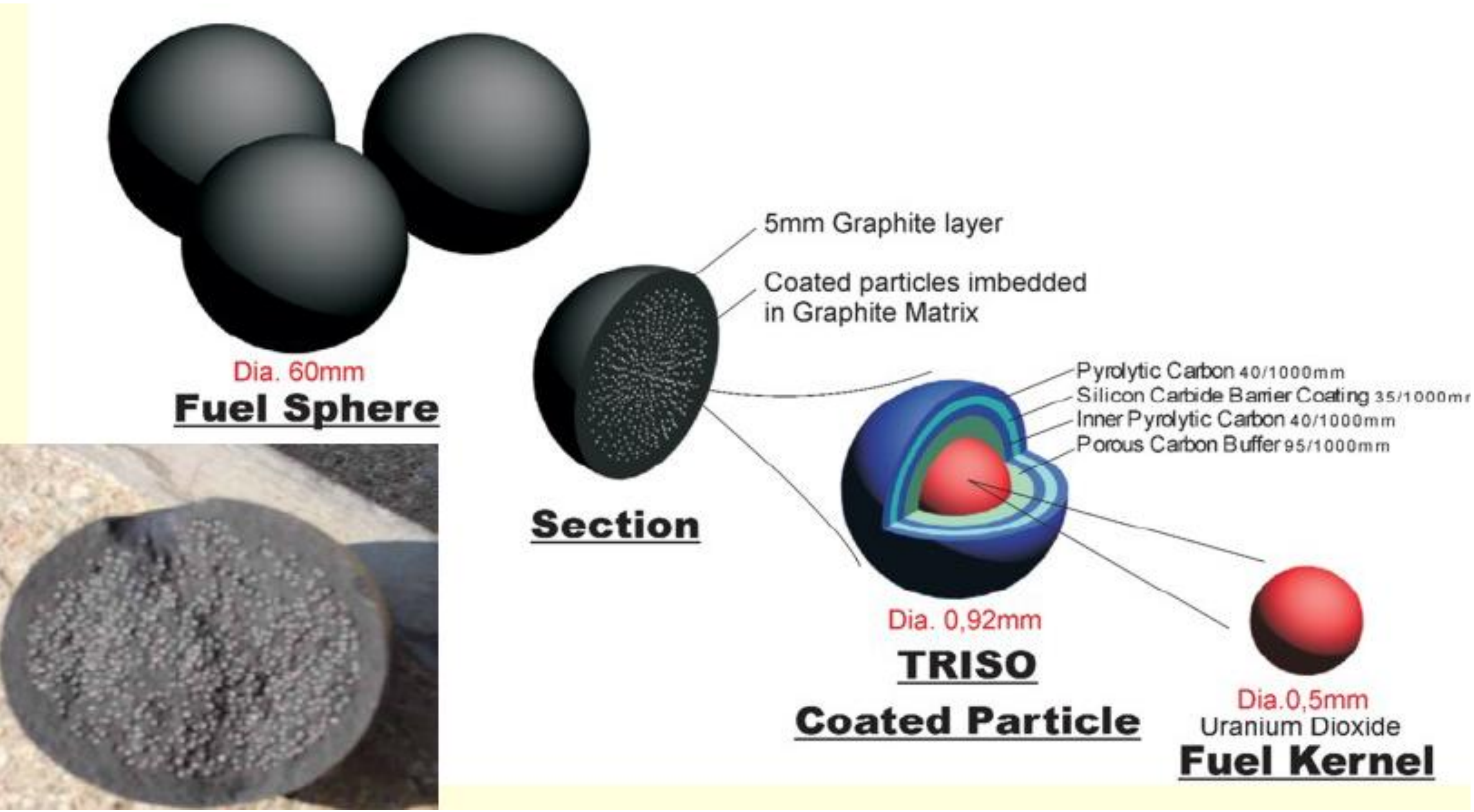






ABTR Primary Vessel

Pebbles!

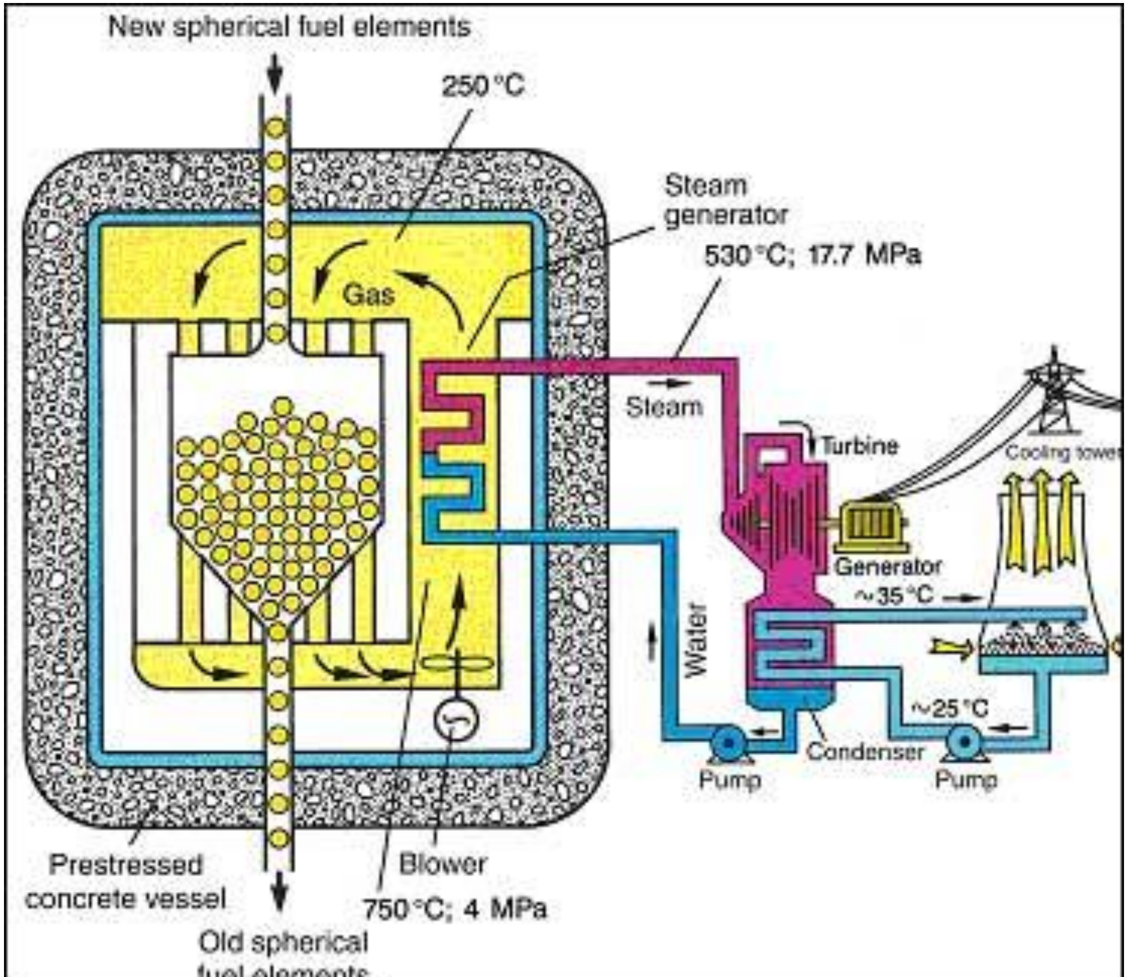


5mm Graphite layer
Coated particles imbedded in Graphite Matrix
Dia. 60mm
Fuel Sphere
Section
Pyrolytic Carbon 40/1000mm
Silicon Carbide Barrier Coating 35/1000m
Inner Pyrolytic Carbon 40/1000mm
Porous Carbon Buffer 95/1000mm
Dia. 0,92mm
TRISO
Coated Particle
Dia.0,5mm
Uranium Dioxide
Fuel Kernel

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:
  - 900μm TRISO particle
  - ~15,000 particles per pebble
- Enrichment: 7-10%

Pebble Bed Reactors

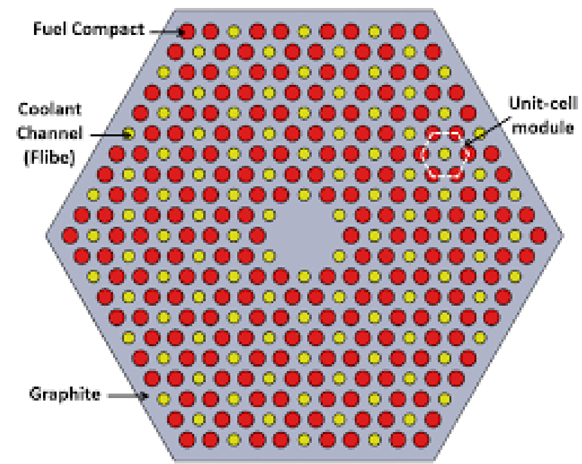


- Several types, PBMR well known
- Power controlled by adding or removing helium coolant—no control rods
- Pebble recycling maintains constant reactivity and achieves very high fuel burnup

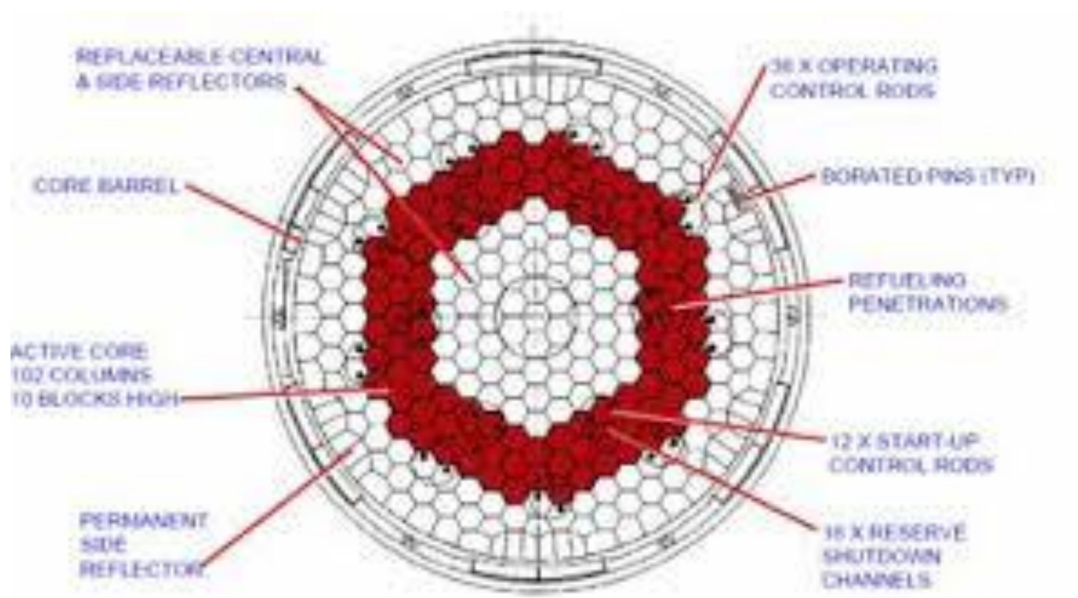
TRISO Particles as Fuel Compacts for Prismatic Fuel


PARTICLES


COMPACTS



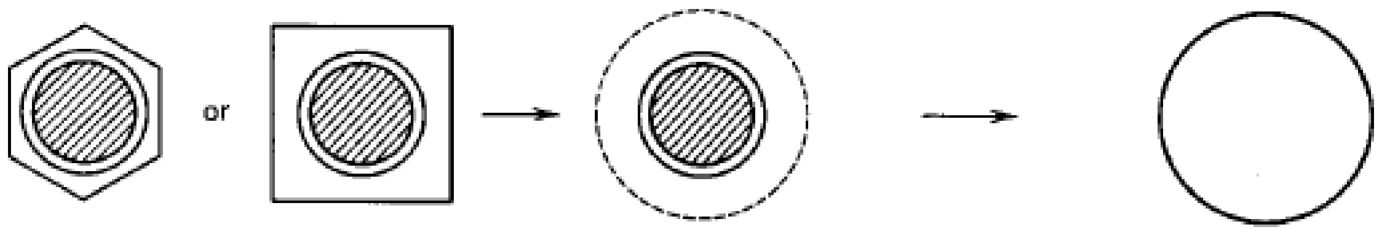

FUEL ELEMENTS



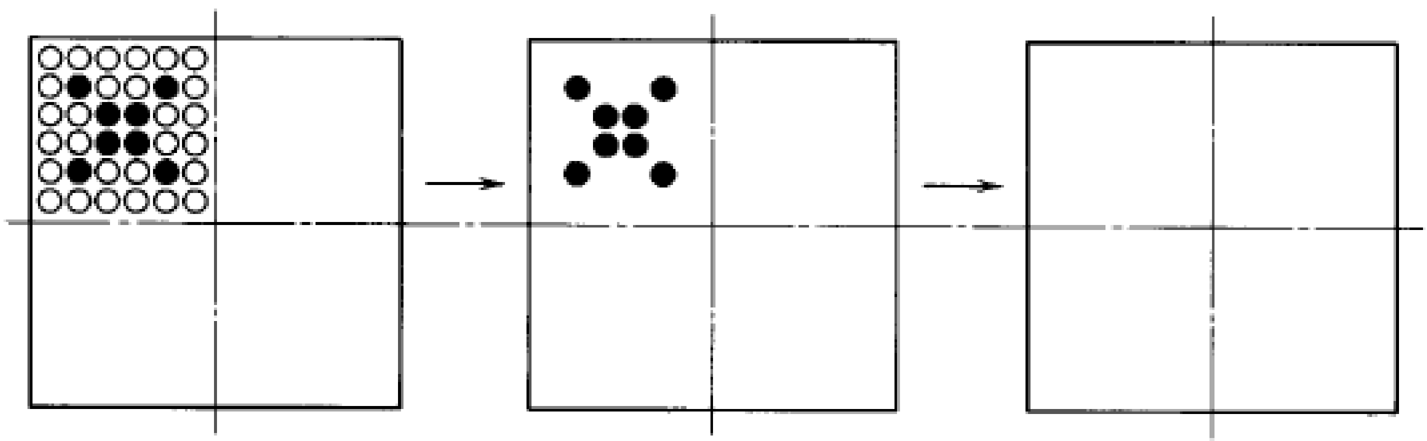
HTGR Prismatic Fuel

- Dimensions: hexagonal, H=0.8m, 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=0.8m
  - Contains 14-15 “compacts” with 350-500μm TRISO particles
- Enrichment: 8-20%
- May have separate B_4C burnable poison rods

Simplifications

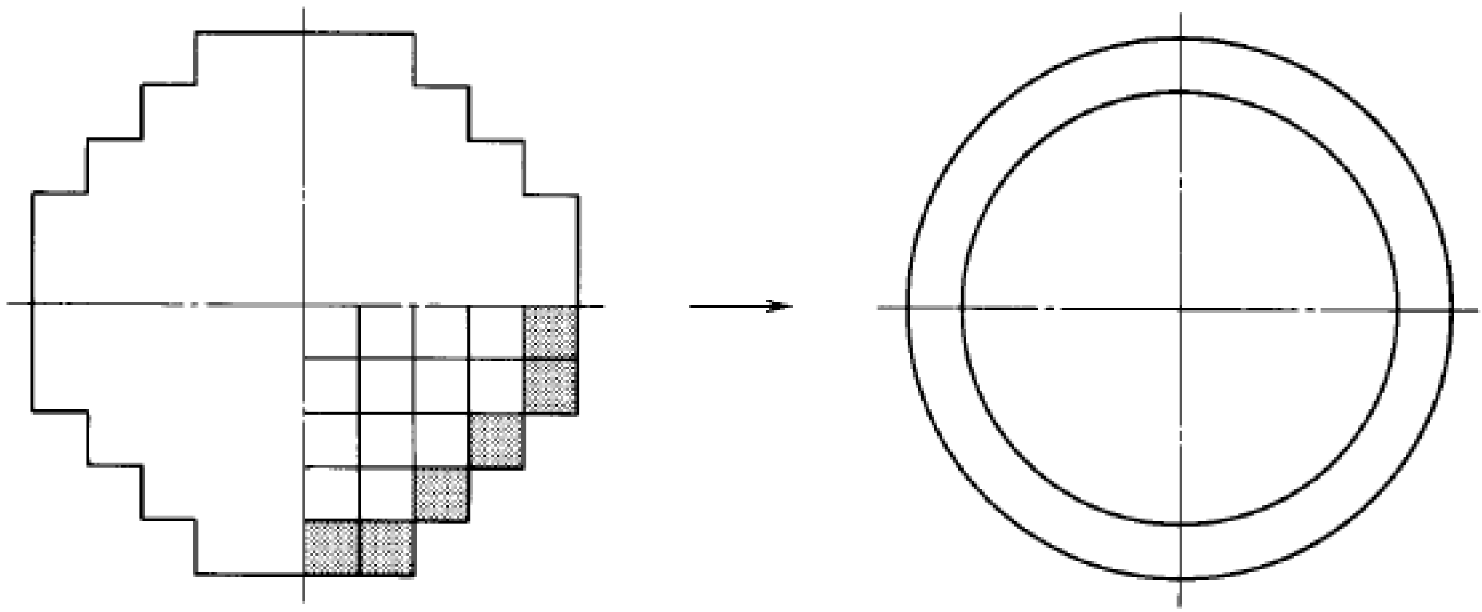


(a) Fuel-cell homogenization



(b) Fuel-assembly homogenization

Simplifications

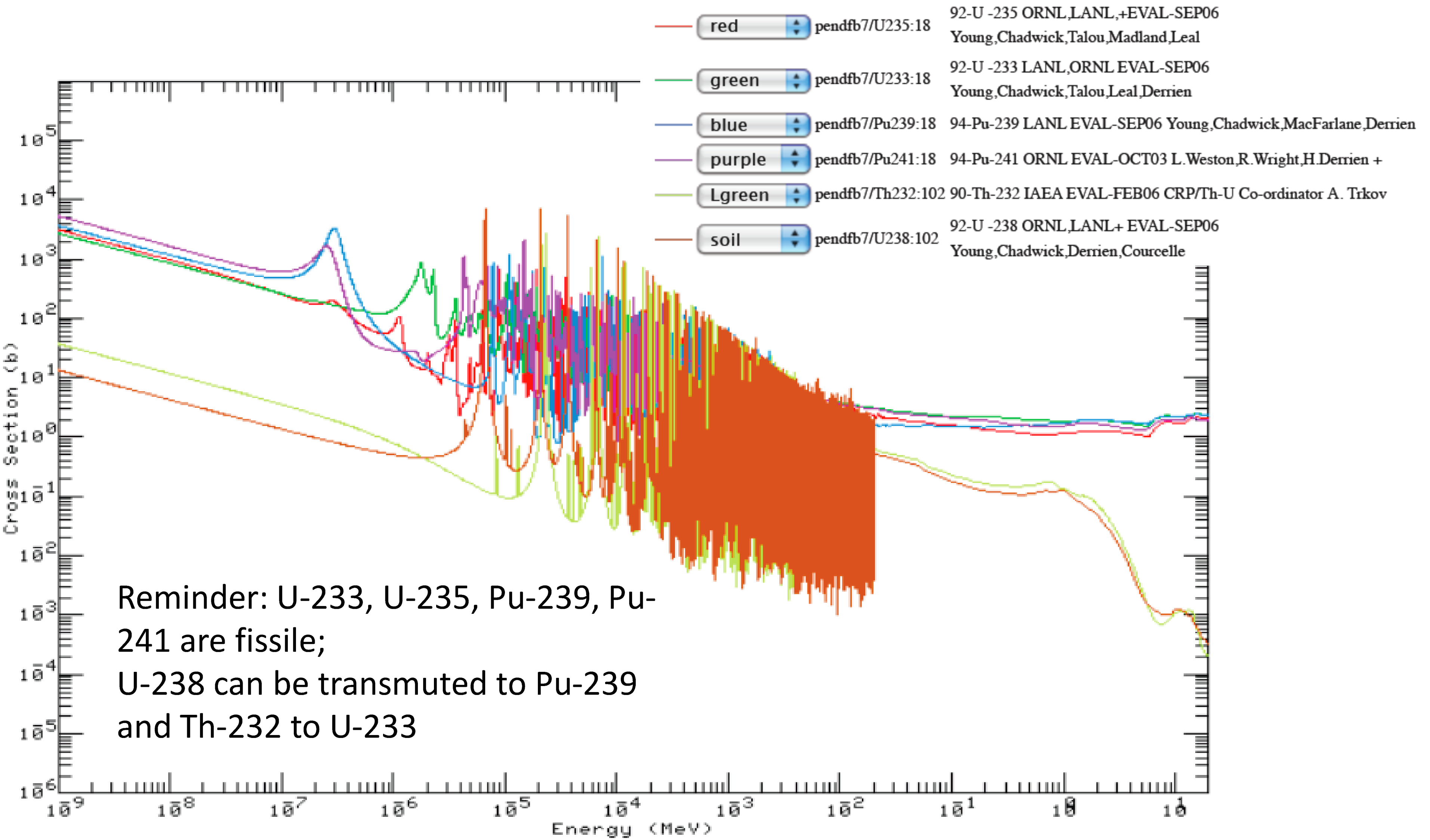


(c) Core homogenization

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

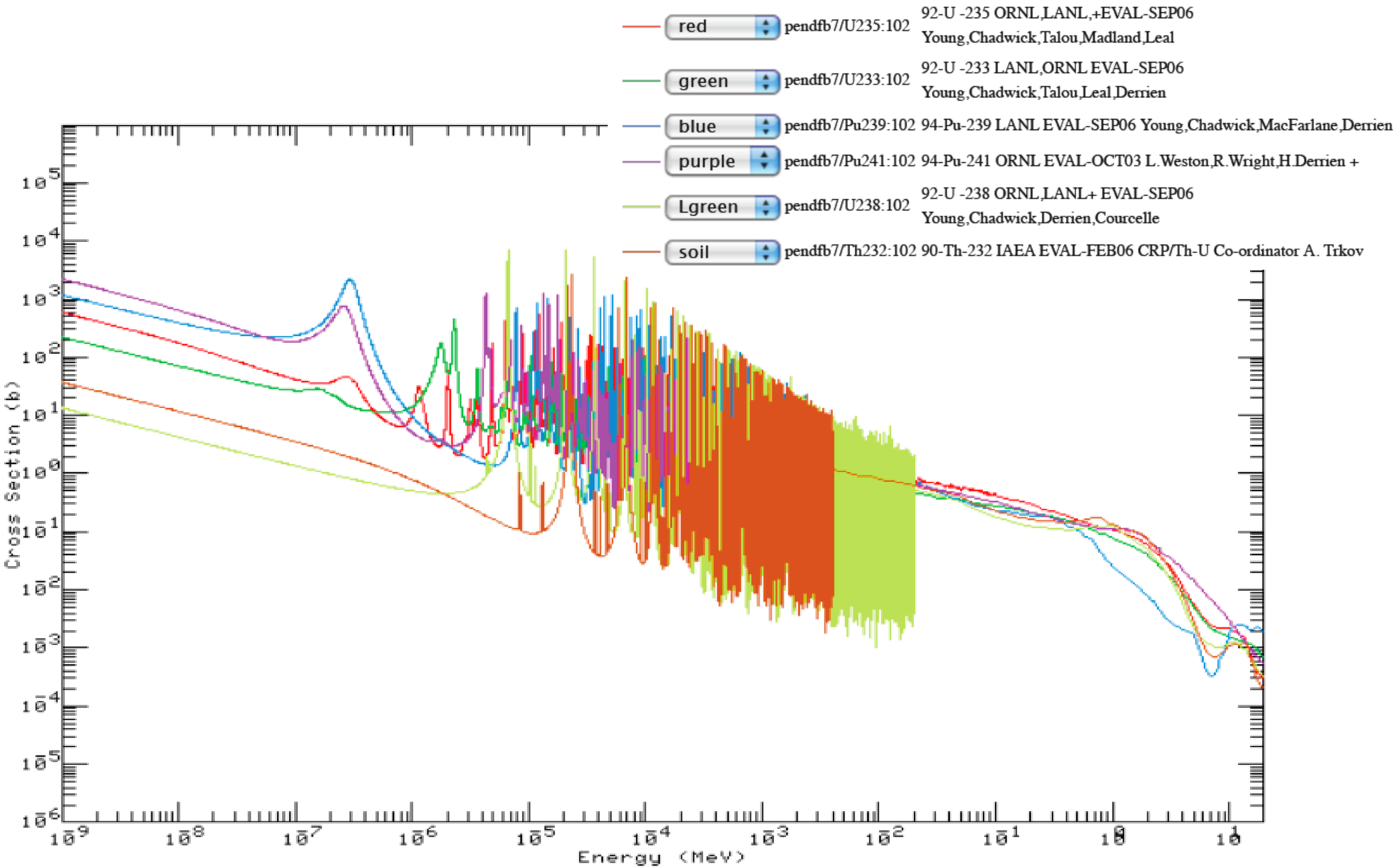
http://atom.kaeri.re.kr/



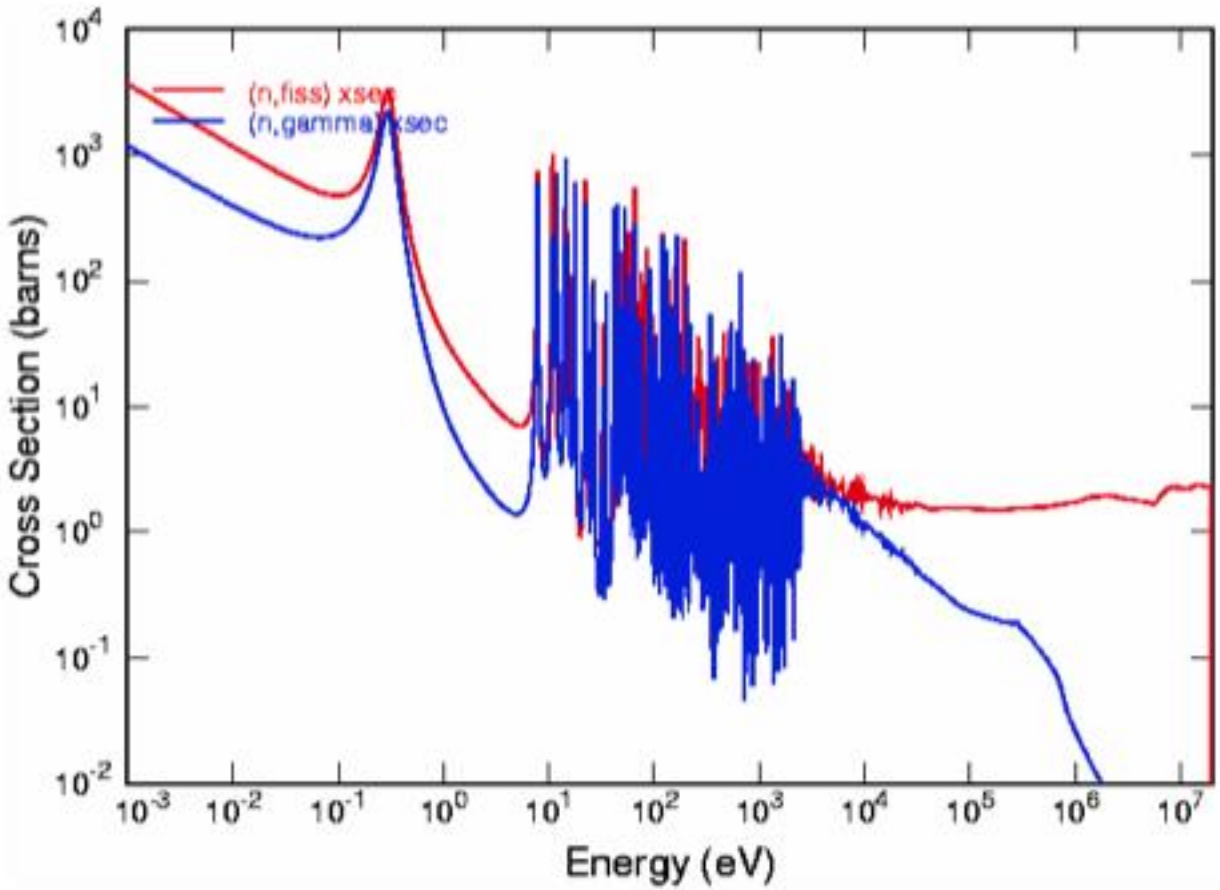
Reminder: U-233, U-235, Pu-239, Pu-241 are fissile;

U-238 can be transmuted to Pu-239 and Th-232 to U-233

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

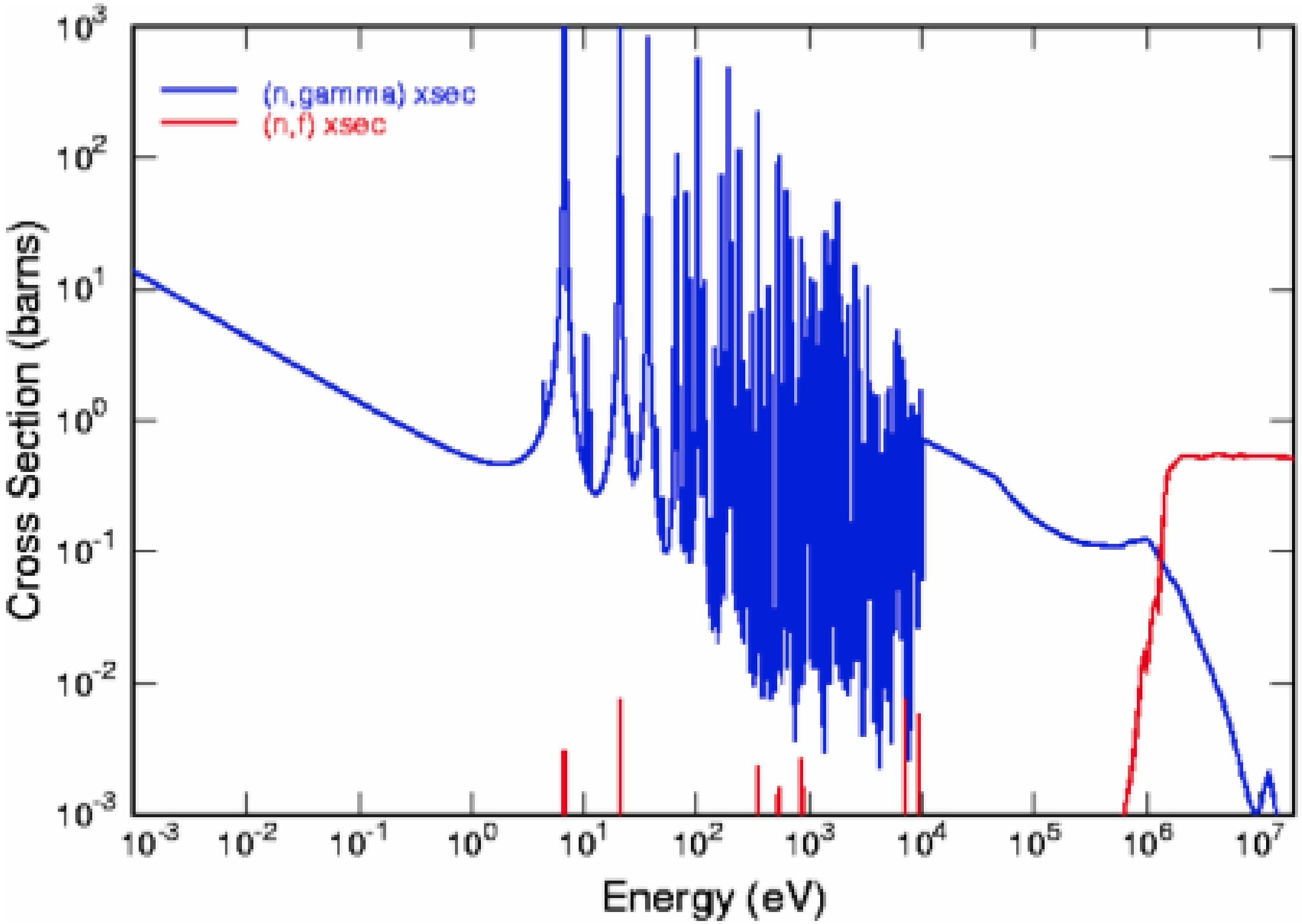


Spectral Variations of Neutron Cross Sections: Pu-239



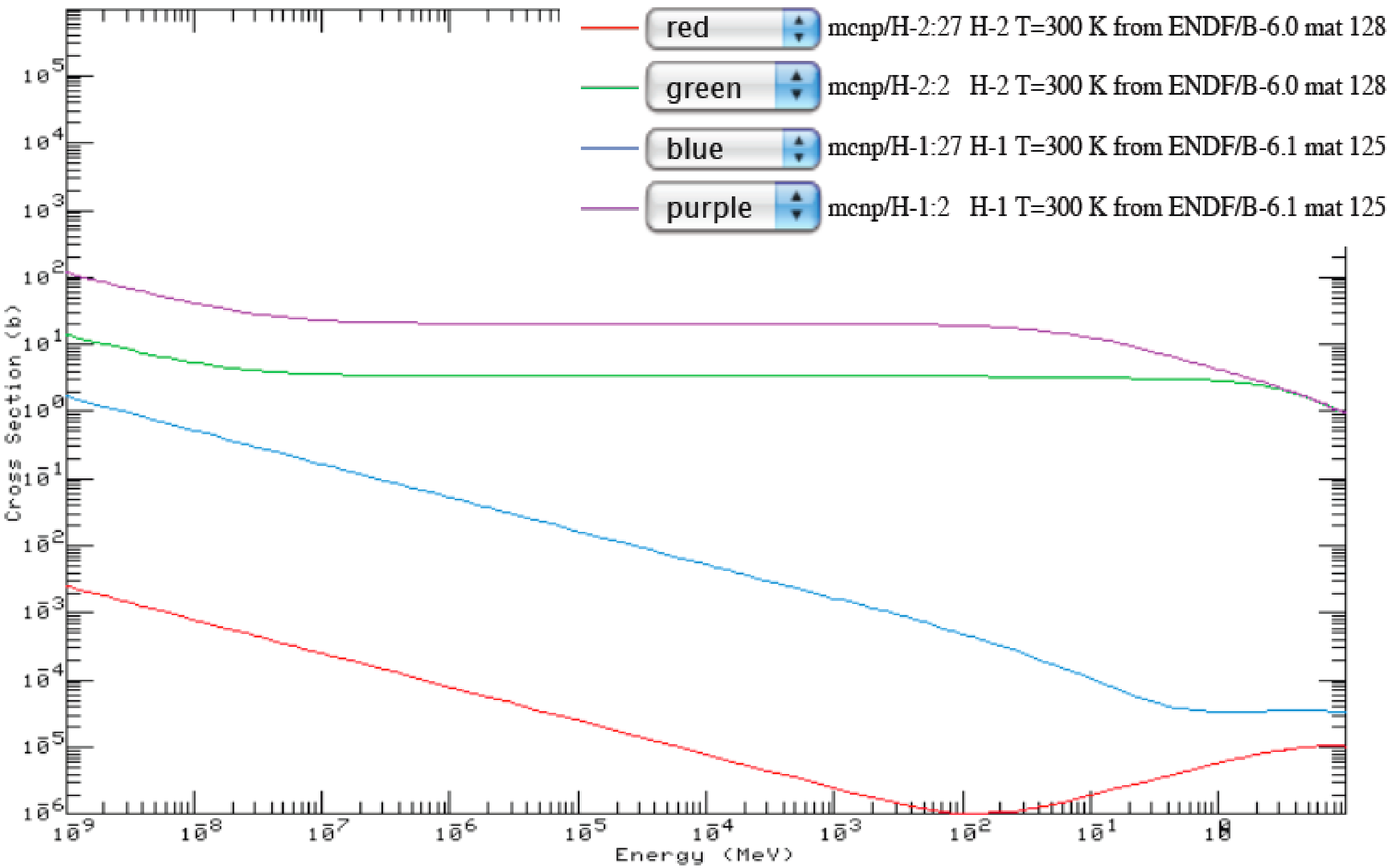
- Fission and capture cross sections > 100 x larger in thermal neutron energy region
- Sharp decrease in capture cross sections in at high neutron energy

Spectral Variations of Neutron Cross Sections: U-238

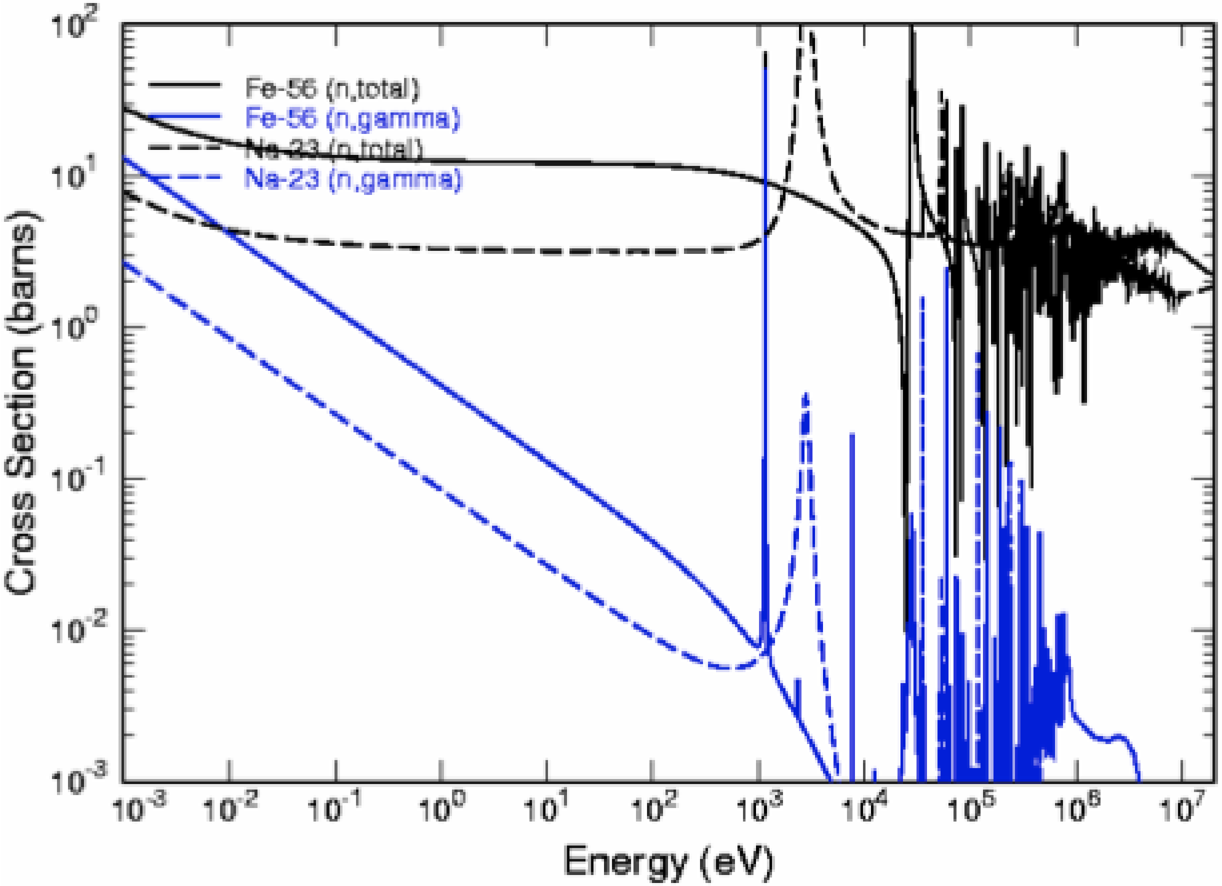


- Fission threshold at ~ 1MeV
- Unresolved resonance region begins at ~ 10 keV

Elastic scattering and capture cross sections for H and D

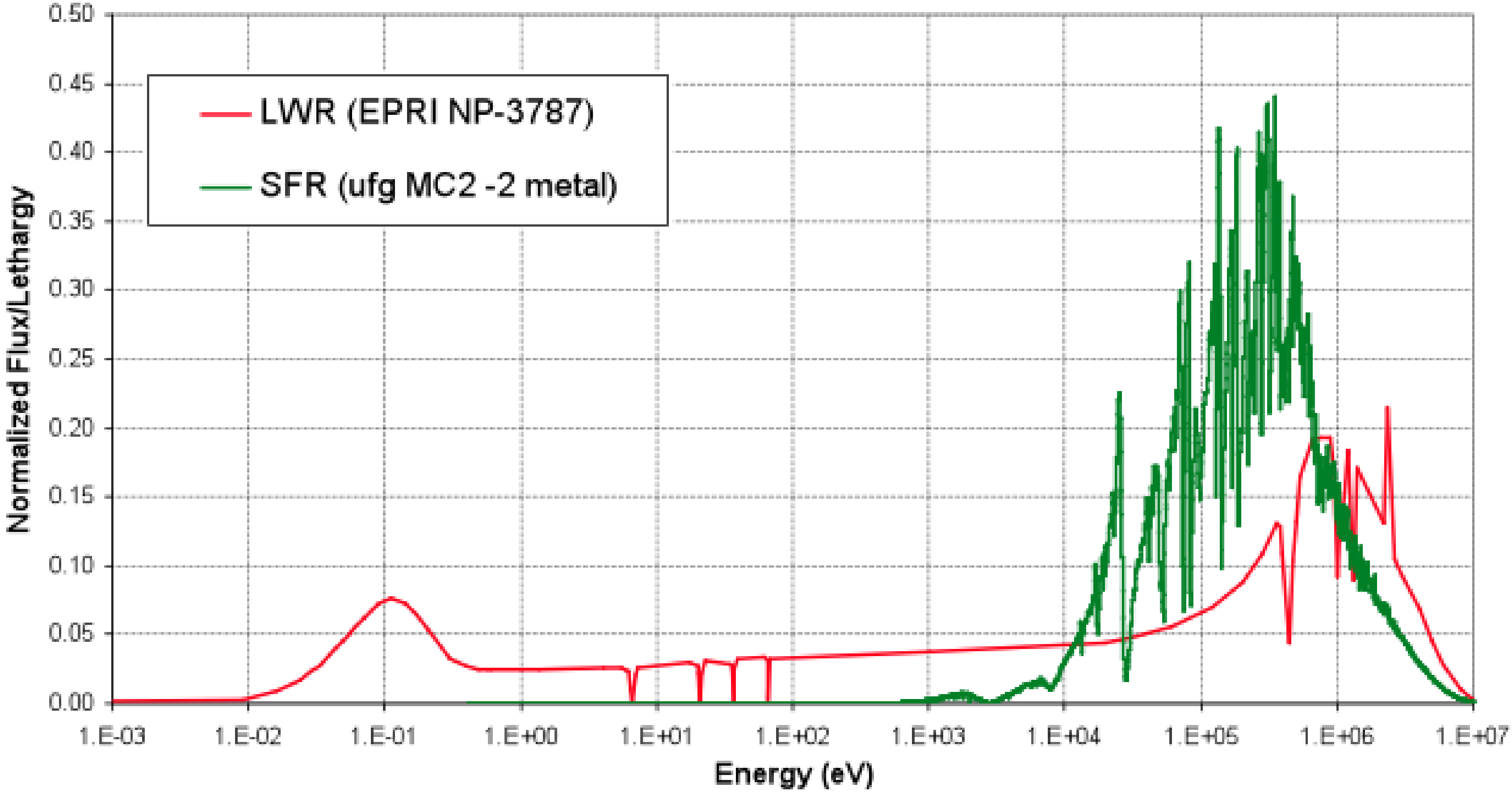


Spectral Variations of Neutron Cross Sections: Na and Fe



- 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