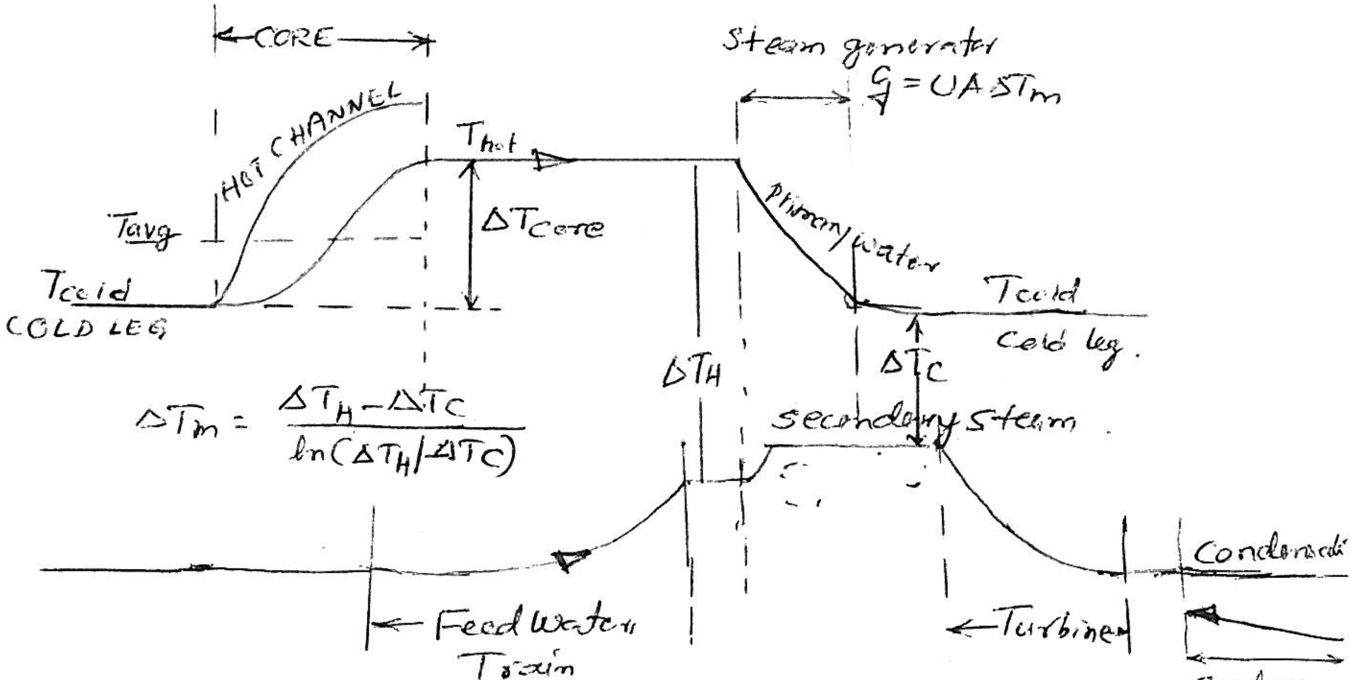
Thermal Design Principles

- Primary system temperature and pressure
  - coolant selection and plant thermal performance



- Plant Temperature (PWR)

LWR Thermal Conditions

	PWR	BWR
Tout primary	324°C	288°C
P. "	15.5 MPa	7.17 MPa
P - turbine condition	5.7 MPa	7.17 MPa
T "	272.3°C	287.5°C
Plant thermal efficiency	33.5%	32.9%

Energy Production and Heat Transfer

Core power : $\dot{Q}$

Core power density : $\dot{Q}/V = \dot{Q}'''$

Core specific power : $\dot{Q}$ / mass of heavy atoms.

volumetric heat generation rate : $q'''(\vec{r})$

Surface heat flux : $\vec{q}''(s)$

Linear heat-generation rate : $q'(z)$

Rate of energy generation per pin: $\dot{q}$

$$\iint_S \vec{q}''(s) \cdot \vec{n} ds = \iiint_V q'''(\vec{r}) dV$$

$$\int_L q'(z) dz = \iiint_V q'''(\vec{r}) dV$$

$$\dot{q} = \iiint q'''(\vec{r}) dV$$

V = volume of fuel pin

$$\dot{Q} = \sum_{n=1}^{N} \dot{q}_n$$

$$\dot{Q} = N \langle \dot{q} \rangle = NL \langle q' \rangle = NL\pi D_{co} \langle q''_{co} \rangle$$

$$= NL\pi R_{fo}^2 \langle q''' \rangle$$

D_{co} = clad outside diameter

R_{fo} = fuel pellet radius

Thermal Design Limits

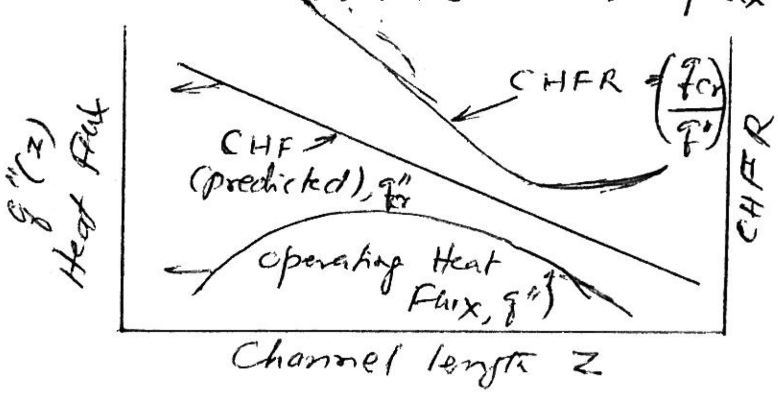
- Required for the integrity of the clad.

Typical Values

Characteristics	PWR	BWR	LMFBR
Damage limit	1% clad strain or MDNBR ≤ 1.0	1% clad strain MCPR ≤ 1.0	0.7% clad strain
Design limits			
Fuel Centerline Temp.			
Steady S.	—	—	—
Transient	No incipient melt	=	=
Clad. Ave. Temp.			
S.S	—	—	1200–1300°F
Transient	< 2200°F (LOCA)	=	1450° (788°C)
Surface Heat flux			
S.S.	—	MCPR ≥ 1.2	—
Transient	MDNBR ≥ 1.3 at 112% power	—	—

MCPR – minimum critical power ratio
MDNBR – minimum departure from nucleate boiling.

- CHF – critical heat flux



Thermal Design Margin

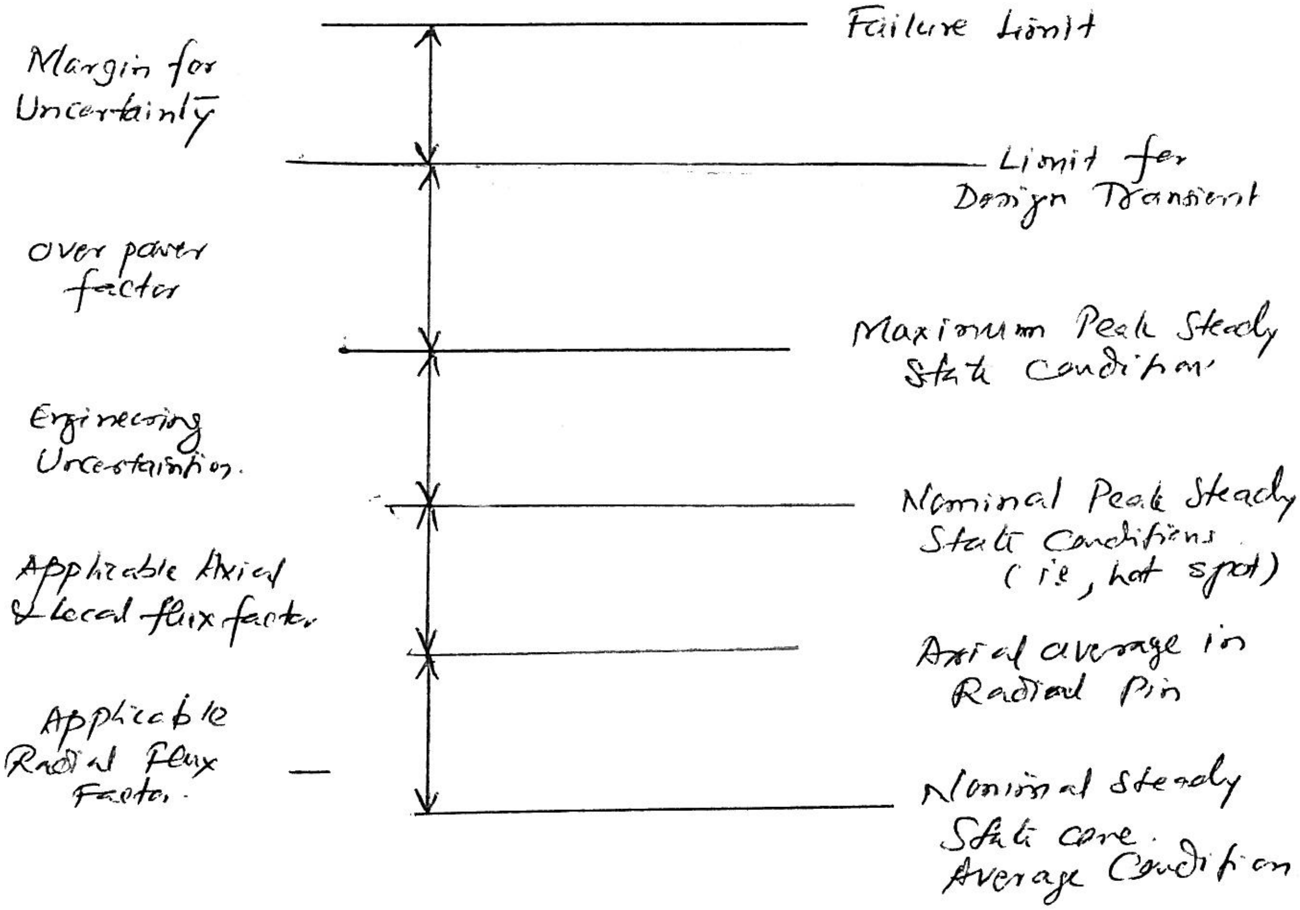
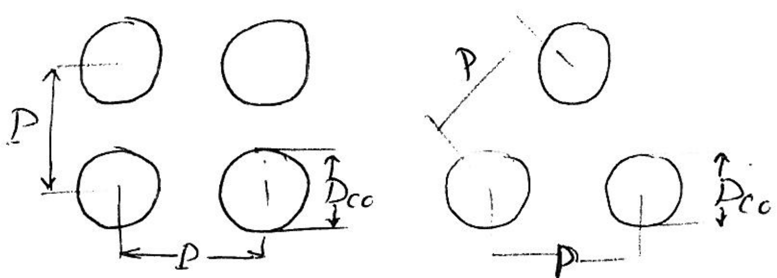


Figure of Merit for Core thermal Performance.

Power Density: Energy generated relative to core volume.



$$Q''' = \frac{4\left(\frac{1}{4}\pi R_{fo}^2\right) q''' dz}{P^2 dz} = q'/P^2$$

$$Q''' = \frac{3\left(\frac{1}{6}\pi R_{fo}^2\right) q''' dz}{\frac{P}{2}\left(\frac{\sqrt{3}}{2}P\right) dz} = \frac{q'}{\frac{\sqrt{3}}{2} P^2}$$

Specific power – energy generated per unit mass of fuel material.

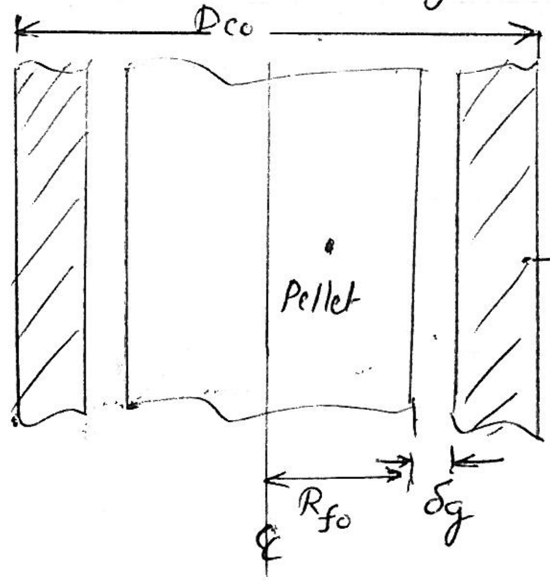
$$\text{Specific power} = \frac{\dot{Q}}{\text{mass of heavy atoms}} = \frac{q'}{\pi R_{fo}^2 \rho_{pellet} f}$$

$$= \frac{q'}{\pi (R_{fo} + \delta_g)^2 \rho_{smeared} f}.$$

$$\rho_{smeared} = \frac{\pi R_{fo}^2 \rho_{pellet}}{\pi (R_{fo} + \delta_g)^2}$$

f = mass fraction of heavy atoms in fuel

$$= \frac{\text{grams of fuel heavy atoms}}{\text{grams of fuel.}} = \frac{r M_{ff} + (1-r) M_{nf}}{r M_{ff} + (1-r) M_{nf} + M_{O}}$$



r – enrichment
ff – fissionable fuel
nf – non " "
M – molecular weight