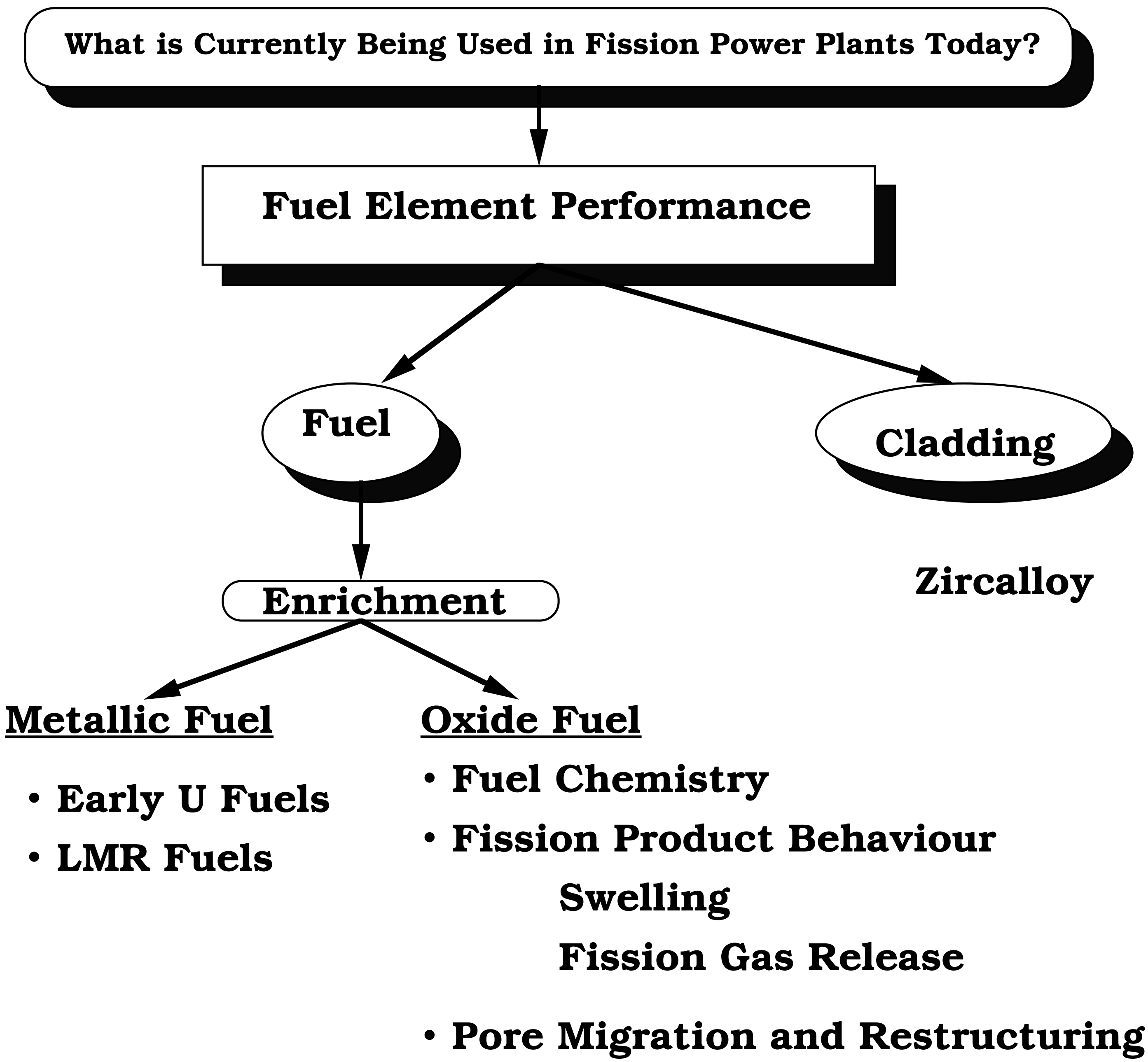

What is Currently Being Used in Fission Power Plants Today?
Fuel Element Performance
Fuel
Cladding
Enrichment
Zircalloy
Metallic Fuel
• Early U Fuels
• LMR Fuels
Oxide Fuel
• Fuel Chemistry
• Fission Product Behaviour
Swelling
Fission Gas Release
• Pore Migration and Restructuring

<u>Metallic</u> <u>Fuels</u>

- **During first 10 years of fission reactor research almost all fuels were metallic.**
- **Now (see last lecture) practically all power reactor fuels are oxides.**
- **Need fissionable isotope U^{235},**

  $t_{\frac{1}{2}}$ =710 million years

Uranium

Phases

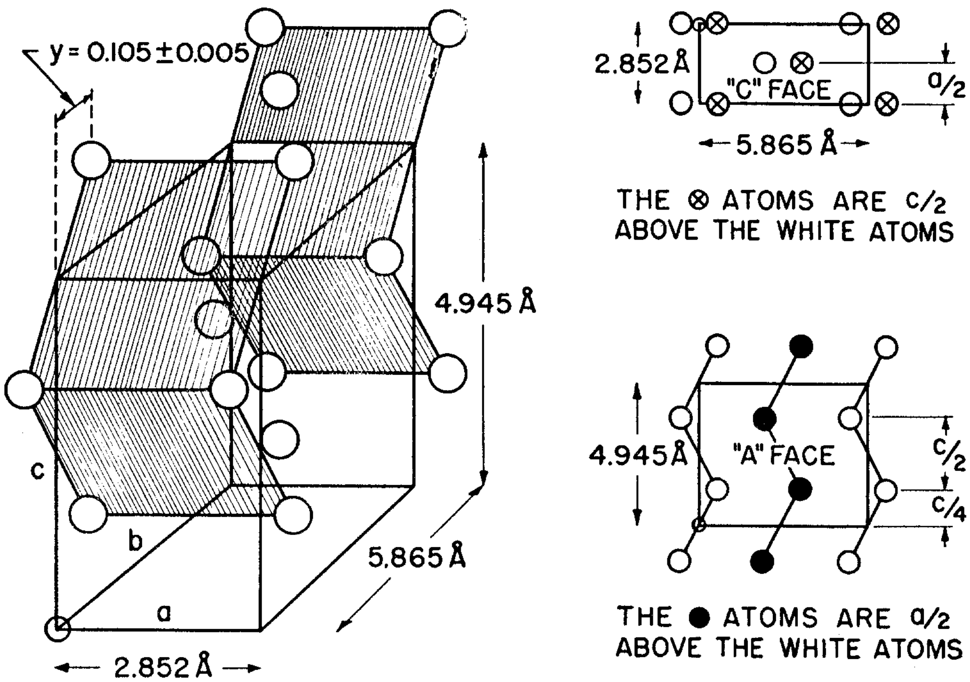
α =orthorhombic-----------$a \neq b \neq c$

β = tetragonal -----------$a = b \neq c$

γ = body centered cubic--$a = b = c$

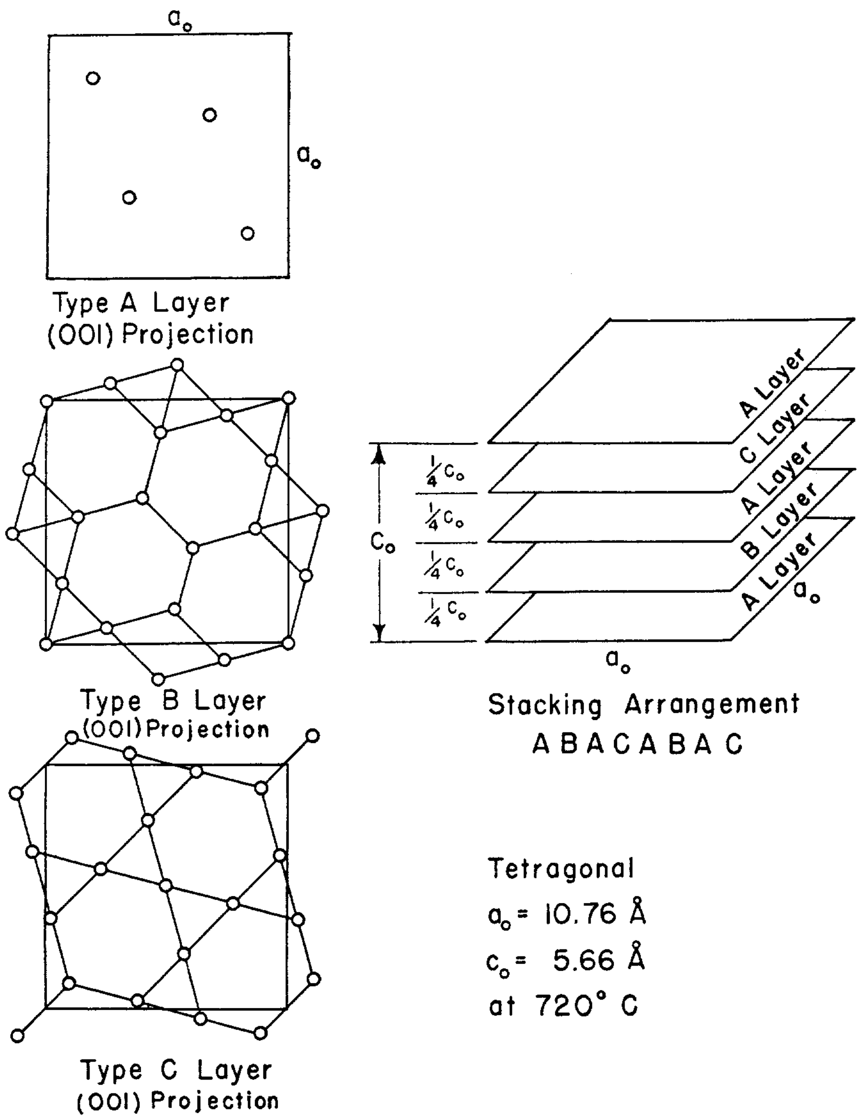
(figure)

Anisotropy of Alpha Uranium Phase		
Lattice Direction	Å	Thermal Expansion Coefficient °C^{-1} x 10^{-6} (25-125)
100	2.852	21.17
010	5.685	-1.15
001	4.945	23.2
		Volume 45.8



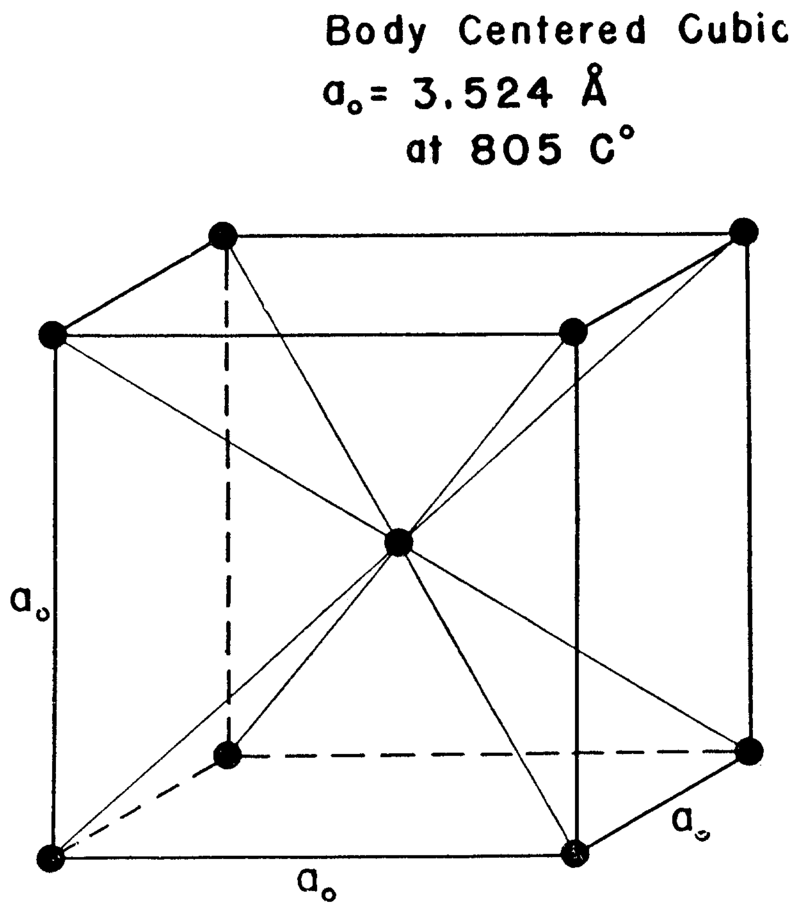
The crystal structure of alpha uranium.

Nuclear Reactor Metallurgy, Walter D. Wilkinson and William F. Murphy, D. Van Nostrand Co., Inc., 1958.



The crystal structure of beta uranium.

Nuclear Reactor Metallurgy, Walter D. Wilkinson and William F. Murphy, D. Van Nostrand Co., Inc., 1958.



The crystal structure of gamma uranium.

Nuclear Reactor Metallurgy, Walter D. Wilkinson and William F. Murphy, D. Van Nostrand Co., Inc., 1958.

Dimensional Stability

1.) Irradiation Growth
Change of shape without appreciable volume change

2.) Irradiation Creep
Change of shape under an external stress

3.) Swelling
No change of shape but a change in volume

Plus two other phenomena NOT related to irradiation !

A.) Thermal Racheting

Thermal cycling of polycrystal textured specimen in α phase

B.) Surface Roughing

Cycling through the α–β phase transition

<u>Necessary</u> <u>Definitions</u>

Problem: ***What unit to use in describing radiation damage in fissile material?***

Properties are more related to fission events than to neutron fluence

----

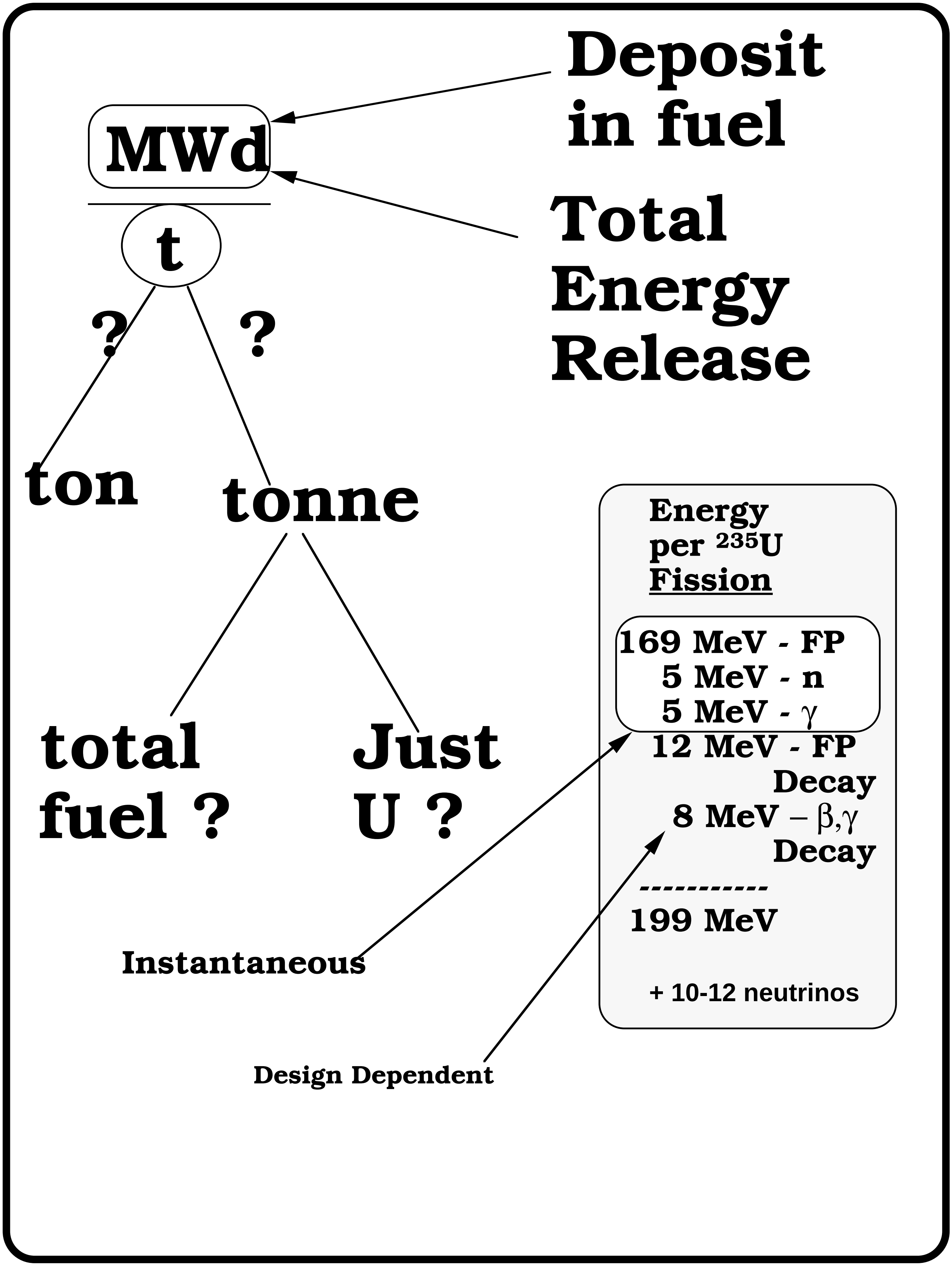
No single definition satisfactory!

A.) Reactor Designer - More concerned with power density than fission density

B.) Reactor Physicist- More concerned with percentage of fissile atoms lost by all processes than with % fissioned

C.) Material Scientists- Can't agree! i.e., a 70% burnup of U atoms in UO_2 -Steel cermet means more than

3×10^{21} fissions/cm^3


MWd
t
Deposit in fuel
Total Energy Release
?
?
ton
tonne
total fuel ?
Just U ?
Energy per ^{235}U Fission
169 MeV - FP
5 MeV - n
5 MeV - γ
12 MeV - FP Decay
8 MeV – β,γ Decay
----
199 MeV
+ 10-12 neutrinos
Instantaneous
Design Dependent

Another Unit Which is Misinterpreted -

$$\frac{Fission}{cm^3}$$

- Necessary for heat transfer calculations

• What is included in cm^{-3} ?

Normally it is not the cladding or the coating on the fuel pellets

$$\frac{Fission}{cm^3} = (\text{frac. of U atoms fissioned}) \cdot (\text{density of U in fuel})$$

$$= \frac{N_f}{N_U} \cdot \{nvt\sigma_f\} \cdot \frac{\rho N_A}{m'}$$

where;

$\frac{N_f}{N_U}$ = **fraction of U atoms that can fission**

ρ= **fuel density**

m' = M. Wt. of fuel/# of U atoms in molecule

N_A = **Avogadros Number**

Relate Burn -up and Integral Flux

Let N = atoms of fissile isotopes

σ_c, σ_f = capture and fission xsections, respectively

$$\frac{dN}{dt} = -Nnv\sigma_a$$

where $\sigma_a = \sigma_c + \sigma_f$

Integrating and finding the % of fissile atoms lost, one finds;

$$100\left\{\frac{(N_o - N)}{N_o}\right\} = 100\left\{1 - e^{-nvt\sigma_a}\right\}$$

The % of atoms fissioned is then;

$$100\left[\frac{\sigma_f}{\sigma_a}\right]\left\{1 - e^{-nvt\sigma_a}\right\}$$

when $nvt\sigma_a$ << 1, exp (-x) ≈ 1-x,

% atoms fissioned = 100 $nvt\sigma_f$

---

since σ_f ≈ 550 barns for ^{35}U in thermal flux;

% B.U. of ^{35}U atoms = 55000 b • (nvt)

If only a fraction of U atoms are fissionable;

$$\frac{N_f}{N_U}\left[100 \cdot nvt\sigma_f\right]$$

Example

- **Assume 1 fission = 200 MeV**

$$\left(200 \cdot 10^{6} \frac{eV}{fission}\right) \cdot \left(1.6 \cdot 10^{-19} \frac{watt-s}{eV}\right) \cdot \left(\frac{1 day}{86,400 s}\right)$$

$$= 3.7 \cdot 10^{-16} \frac{watt-d}{fission}$$

$$\frac{watt-d}{g_{fuel}} = 3.7 \cdot 10^{-16} \cdot \left(\frac{1}{\rho_{fuel}}\right) \cdot \left(\frac{fissions}{cm^{3}}\right)$$

or, $$\frac{MWd}{tonne-U} = 3.7 \cdot 10^{-16} \cdot \left(\frac{1}{\rho_{fuel}}\right) \cdot \left(\frac{fissions}{cm^{3}}\right) \cdot \frac{m'}{A}$$

where A = atomic wt. of U

What if not all of the energy released is captured by the fuel?

- **can only count on 169 MeV K.E. of FP's**
  Plus <u>12 MeV</u> Decay of FP's

$$\frac{MWd}{tonne-fuel} = 1.85 \cdot 10^{-18} \cdot \left(\frac{1}{\rho_{fuel}}\right) \cdot \left(\frac{fissions}{cm^{3}}\right) \cdot E_{f}$$

where E_f is the fission energy (MeV) deposited in the fuel

Another way to express this is:

$$\frac{MWd-in-fuel}{tonne-U} = 1.85 \cdot 10^{-18} \cdot \left(\frac{E_f}{\rho_{fuel}}\right) \cdot \left(\frac{fissions}{cm^3}\right) \cdot \frac{m'}{A}$$

What Have We Forgotten?

1.) Conversion of fertile to fissile
(important at low enrichments and at high burn up)

2.) Fast fission
Few % in thermal reactors

3.) Absorption of gamma rays
From the parent fuel rod or from surrounding fuel rods

$$\frac{MWd \cdot within \cdot fuel}{tonne \cdot fuel} = \frac{A}{m'} \bullet \left(- \right)$$

$$\frac{MWd \;\; within \;\; fuel}{tonne \;\; U} = 1.85 \bullet 10^{-18} \left(\frac{m' E_f}{\rho A} \right) \bullet \left(- \right)$$

$$\frac{fissions}{cm^3} = 6.02 \bullet 10^{21} \bullet \left(\frac{\rho N_t}{m' N_U} \right) \bullet \left(- \right)$$

$$\% \cdot of \cdot all \cdot atoms \cdot fissioned = \frac{N_U}{N_t} \bullet \left(- \right)$$

$$\% \cdot of \cdot all \cdot U \cdot atoms \cdot fissioned = 100 \frac{N_f \sigma_f}{N_U} \bullet \left(- \right)$$

$$neutron \cdot fluence = nvt$$