1a) $T = 1200\,K$ $\quad \dot{F} = 2E14\ fiss/cm^3 s$

$$D_1 = 7.6\times10^{-6}\, e^{\left(\frac{-3.03\ eV}{8.617333\times10^{-5}\frac{eV}{K}\ 1200K}\right)}$$

$$= 1.4302\times10^{-18}\ cm^2/s$$

$$D_2 = 1.41\times10^{-18}\, e^{\left(\frac{-1.19\ eV}{8.617333\times10^{-5}\frac{eV}{K}\ 1200K}\right)}\sqrt{2\times10^{14}}$$

$$= 2.0048\times10^{-16}\ cm^2/s$$

$$D_3 = 2\times10^{-30}\left(2\times10^{14}\right)$$

$$= 4\times10^{-16}\ cm^2/s$$

$$D_{tot} = D_1 + D_2 + D_3 = 6.0185\times10^{-16}\ cm^2/s$$

1b) $$\tau = \frac{Dt}{a^2} = \frac{\left(6.0185\times10^{-16}\ cm^2/s\right)\left(2\cdot365\cdot24\cdot3600\,s\right)}{\left(8\times10^{-4}\ cm\right)^2}$$

$$= 0.0593 < \pi^{-2}$$

$$f = 4\sqrt{\frac{Dt}{\pi a^2}} - \frac{3}{2}\frac{Dt}{a^2} = 4\sqrt{\frac{0.0593}{\pi}} - \frac{3}{2}(0.0593)$$

$$= 0.46006$$

$$\text{Total FGR} = f\, y\, \dot{F}\, t = (0.46006)(0.3017)(2\times10^{14})(2\cdot365\cdot24\cdot3600\,s)$$

$$= 1.753\times10^{21}\ \frac{atom}{cm^3}$$

1c) $0.3 = 1 - \frac{6}{\pi^2} e^{\left(-\pi^2 \frac{D}{(8\times10^{-4})^2} t\right)}$

$\ln\left(-\frac{\pi^2}{6}(-0.7)\right) = -\pi^2\left(\frac{D}{(8\times10^{-4})^2}\right) t$

$t = \frac{-\ln\left(\pi^2\left(\frac{0.7}{6}\right)\right)(8\times10^{-4})^2}{\pi^2 D}$

~~D has changed~~

~~$D_1 = 7.6\times10^{-6} e^{\frac{-3.03}{k_b T}} = 1.76015\times10^{-13}$~~ $D_1 = 7.6\times10^{-6}$

1.76015×10^{-13}

under the assumption $\tau > \pi^{-2}$ this is always negative!

instead $\tau < \pi^{-2}$ form

$f = 6\sqrt{\frac{Dt}{\pi a^2}} - 3\frac{Dt}{a^2}$

$0.3 = 6\sqrt{\frac{(8E-15)t}{\pi(8\times10^{-4})^2}} - 3\frac{(8E-15)t}{(8\times10^{-4})^2}$

$t = 8.5E7_s$

at old D, $t =$ [illegible] $1E6$?

at D_1 $t = 3.4E5_s$

at $D_{XE} = 8.5E7_s$

2a)

$$6.62\times10^{-7}\exp\left(\frac{11949}{600K}\right)$$

$= 295$ days

$\rightarrow$ past transition

$$\delta^* = 5.1\exp\left(\frac{-550}{600K}\right) = 2.039\ \mu m$$

$$K_L = 7.48\times10^{6}\exp\left(\frac{-12500}{600K}\right) = 0.0067$$

$$\delta = \delta^* + K_L(365-295)$$

$= 2.508\ \mu m$

b) $\varphi = 3\times10^{11}\left(380\frac{W}{cm}\right) = 1.05\times10^{14}\ n/cm^2s$

$$\dot{\epsilon}_{ir} = C_0\varphi^{C_1}\sigma_m^{C_2}$$

$$= (2.846\times10^{-24})(1.05\times10^{14})^{0.85}(300MPa)$$

$= 7.069\times10^{-10}\ /s$

assume constant condition

$$(7.069\times10^{-10}/s)(365\cdot24\cdot3600\ s)$$

0.0223 or 2.23% strain from irradiation (not thermal)

3)

$$\epsilon_{th} = \alpha \Delta T = 11\times10^{-6}(1500)$$

$T \geq 720C \rightarrow C_b = 1$ $\quad = 0.0165$

$$\epsilon_D = 0.01\left(e^{\left(\frac{0.0195 \ln(0.01)}{7\frac{MWD}{kgU}\ \frac{FIMA}{950\frac{MWD}{kgU}}}\right)} - 1\right)$$

$$= -0.01$$

$$\epsilon_{sfp} = 5.577\times10^{-2}(10.97)(0.0195)$$

$$= 0.01193$$

$$\epsilon_{gfp} = 1.96\times10^{-28}(10.97)(0.0195)(1000)^{11.73}\, e^{(-0.0162(1000))}\, e^{(-17.8(10.97)(0.0195))}$$

$$= 0.01328$$

$$\epsilon_{tot} = \epsilon_{th} + \epsilon_D + \epsilon_{sfp} + \epsilon_{gfp}$$

$$= 0.03171 \rightarrow 3.171\%$$

4) Five types of fission products are

- soluble oxides
  - dissolve in cation sublat.
- insoluble oxides
  form oxide in fluorite lat.
- metals
  form precipitates
- volatiles
  gases interior or solids exterior
- noble gases
  insoluble voids or bubbles

5)
1) fission gas production and diffusion to grain boundary
2) grain boundary bubble nucleation, growth, interconnect
3) gas transport through interconnected bubbles to free surfaces

(6)

thermal creep can ~~[illegible]~~ be either Nabarro Herring or Coble creep depending either on elongation along stress axis due to higher or diffision along grain boundaries to elongate along stress axis. Nabarro Herring creep is based on bulk diffusion

7) microstructure based modelling attempts to develop physics based models rather than correlations based. This allows dependence on microstructure rather than burnup and has a potential to be more predictive than the limits of correlation models

8) Zirconium cladding ~~[illegible]~~ has low thermal neutron cross section, has good thermal conductivity and is widely available at a low cost

9) metallic fuel redistributes composition due to Zr Soret diffusion which relocates Zr concentrations into high - low - as fabricated temperatures from center outward. This can affect fuel performance because different phases of fuel form and have different mechanical and thermal properties. For example, the low Zr portion has a lower melting temperature

10) RIA is a reactivity initiated accident, which can lead to a rapid rise in fuel power and temperature. This rise can expand fuel pellets and fission gas, closing the gap, separating at grain boundaries, increasing pressure on clad. This may lead to mechanical interaction between pellet and clad leading to cracking or failure or fuel fragmentation leading to ~~[illegible]~~ dispersal in coolant. If fuel integrity is maintained, a cooling without failure state may be reached

11) ~~Hydride formation and relconcentration occurs~~

non-uniform hydride concentratons occur due to response to temperature and stress. This develops a hydride rim at uniform depth 50-60 μm. Because the response to temperature and stress, these ~~formation~~ concentrations are heterogeneous because both temperature and stress have gradients which concentrate the hydride accordingly.