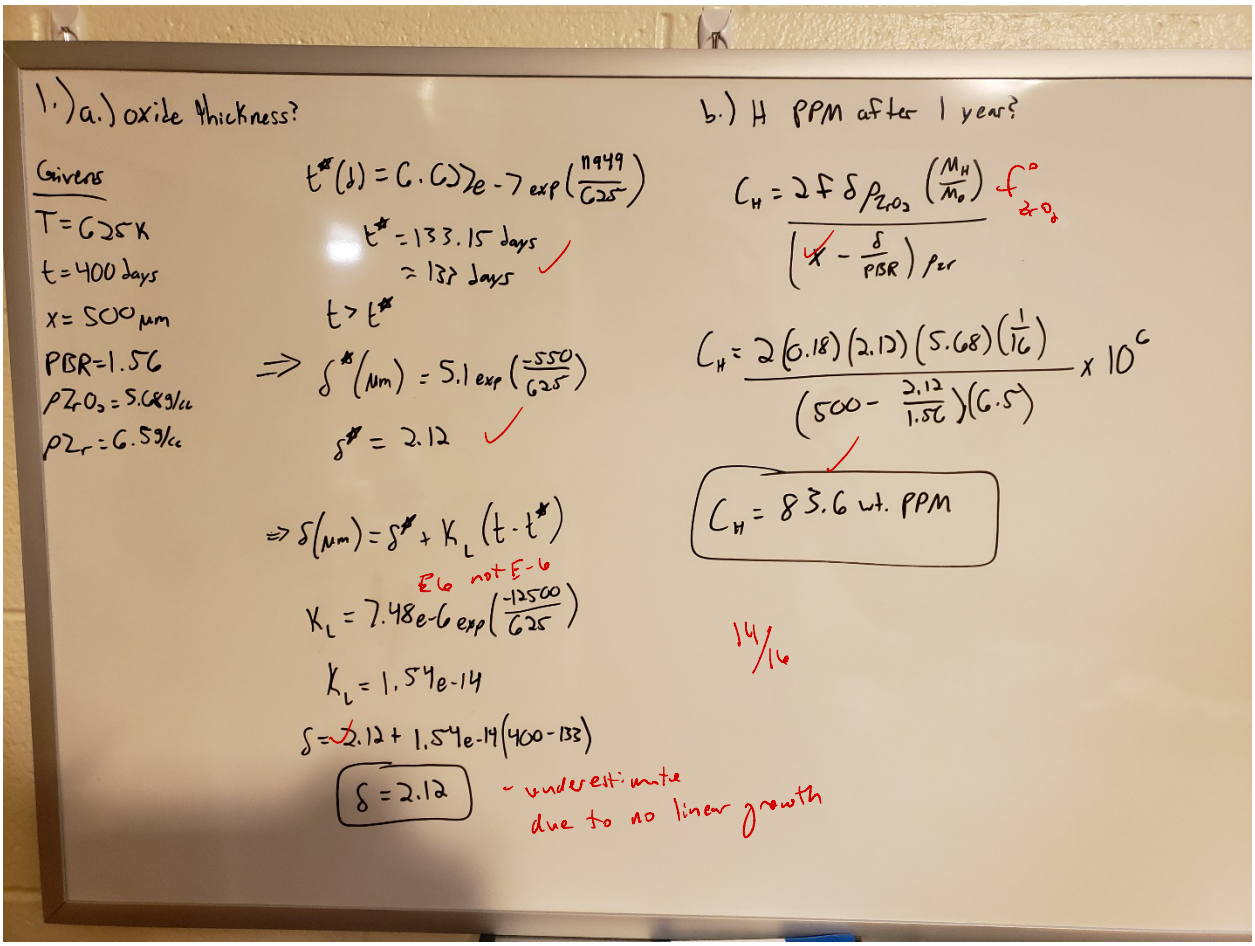
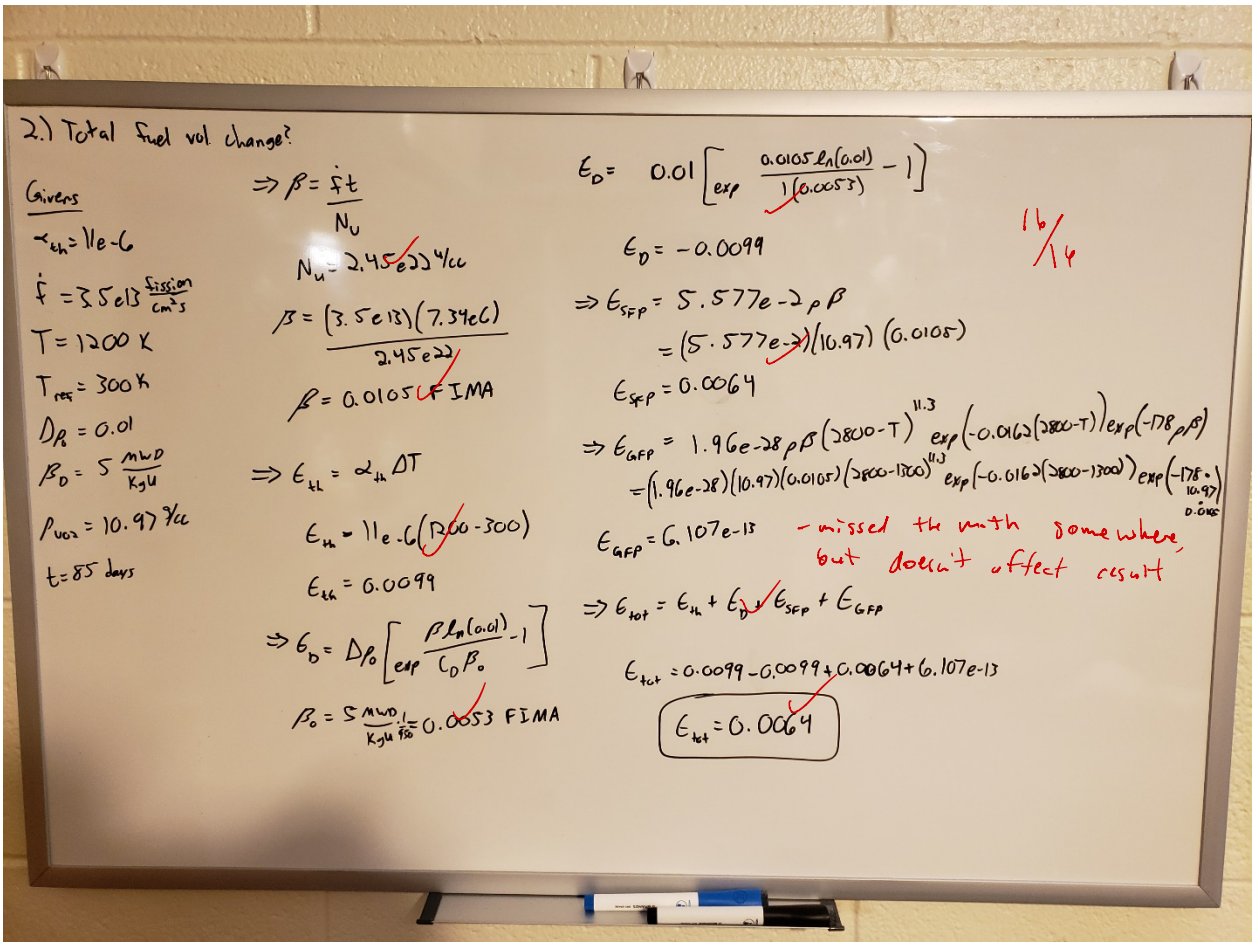
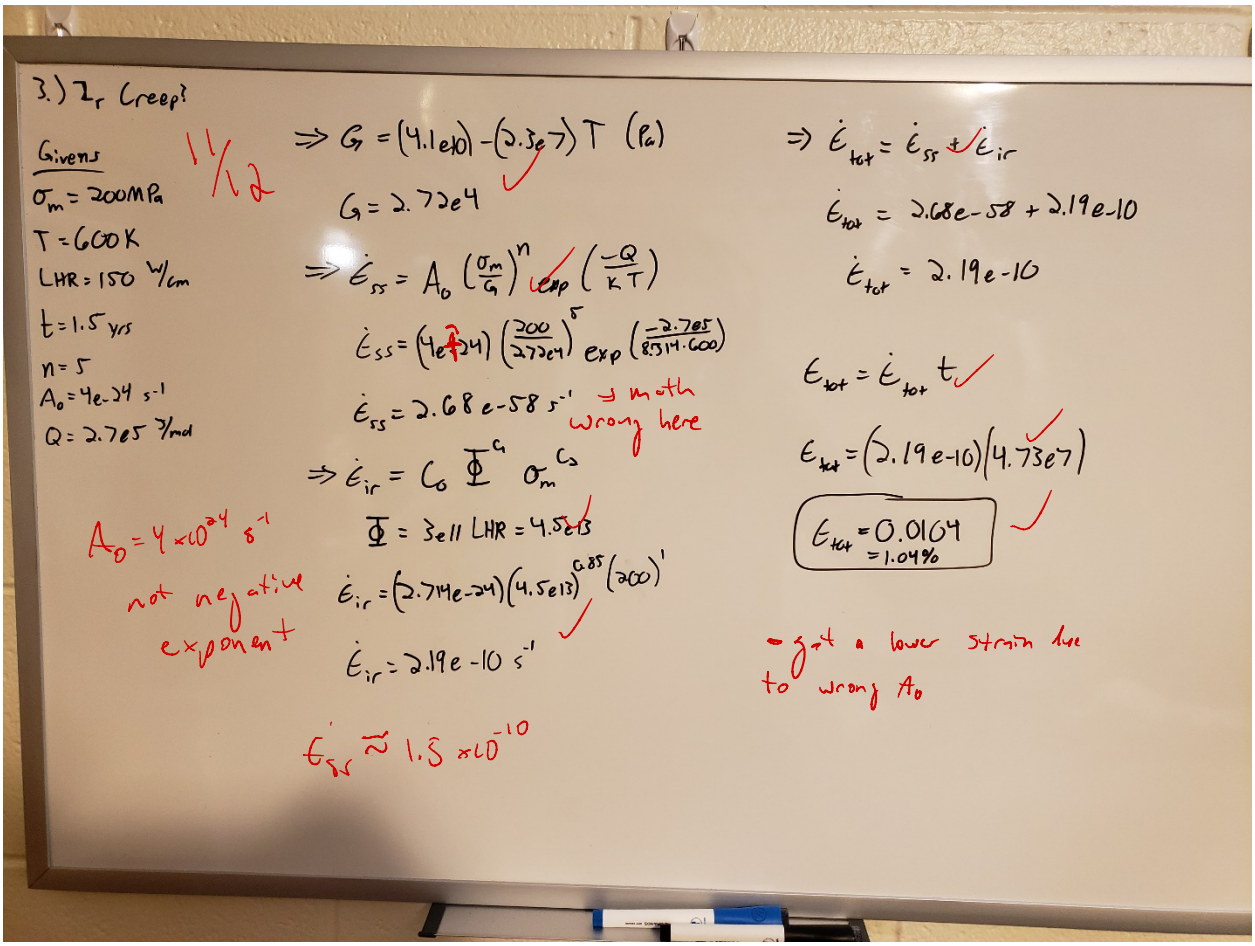
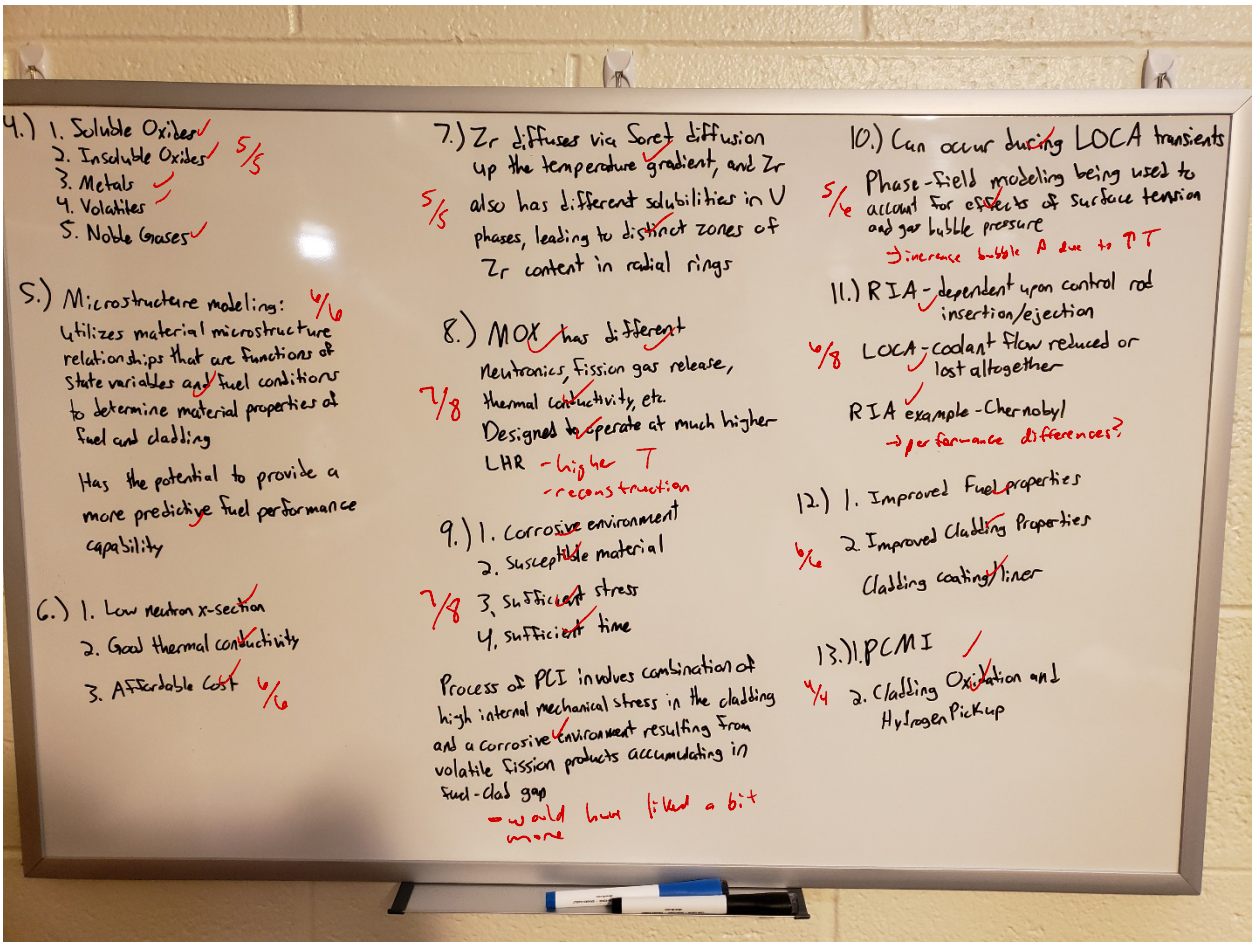

1.) a.) oxide thickness?
Givens
T = 625 K
t = 400 days
x = 500 μm
PBR = 1.56
ρZrO2 = 5.68 g/cc
ρZr = 6.5 g/cc
t*(d) = 6.03e-7 exp(11949/625)
t* = 133.15 days
≈ 133 days
t > t*
⇒ δ*(μm) = 5.1 exp(-550/625)
δ* = 2.12
⇒ δ(μm) = δ* + K_L (t - t*)
E6 not E-6
K_L = 7.48e-6 exp(-12500/625)
K_L = 1.54e-14
δ = 2.12 + 1.54e-14(400 - 133)
δ = 2.12
- underestimate due to no linear growth
b.) H ppm after 1 year?
C_H = 2 f δ ρ_ZrO2 (M_H/M_o) / (x - δ/PBR) ρ_Zr
f = 1
C_H = 2(0.18)(2.12)(5.68)(1/16) / (500 - 2.12/1.56)(6.5) x 10^6
C_H = 83.6 wt. ppm
14/16

100


2.) Total fuel vol. change?
Givens
$\alpha_{th} = 11e\text{-}6$
$\dot{f} = 3.5e13 \frac{\text{fission}}{cm^3 s}$
$T = 1200\ K$
$T_{ref} = 300\ K$
$D_{\rho} = 0.01$
$\beta_D = 5 \frac{MWD}{Kgu}$
$\rho_{UO_2} = 10.97\ g/cc$
$t = 85$ days
$\Rightarrow \beta = \frac{\dot{f} t}{N_U}$
$N_u = 2.45e22$ u/cc
$\beta = \frac{(3.5e13)(7.34e6)}{2.45e22}$
$\beta = 0.0105$ FIMA
$\Rightarrow \epsilon_{th} = \alpha_{th} \Delta T$
$\epsilon_{th} = 11e\text{-}6(1200-300)$
$\epsilon_{th} = 0.0099$
$\Rightarrow \epsilon_D = D_{\rho}\left[\exp\frac{\beta \ln(0.01)}{C_D \beta_0} - 1\right]$
$\beta_0 = 5 \frac{MWD}{Kgu} \frac{1}{950} = 0.0053$ FIMA
$\epsilon_D = 0.01\left[\exp\frac{0.0105 \ln(0.01)}{1(0.0053)} - 1\right]$
$\epsilon_D = -0.0099$
16/14
$\Rightarrow \epsilon_{SFP} = 5.577e\text{-}2 \rho \beta$
$= (5.577e\text{-}2)(10.97)(0.0105)$
$\epsilon_{SFP} = 0.0064$
$\Rightarrow \epsilon_{GFP} = 1.96e\text{-}28 \rho \beta (2800-T)^{11.3} \exp(-0.0162(2800-T)) \exp(-178 \rho \beta)$
$= (1.96e\text{-}28)(10.97)(0.0105)(2800-1300)^{11.3} \exp(-0.0162(2800-1300)) \exp(-178 \cdot \frac{10.97}{0.0105})$
$\epsilon_{GFP} = 6.107e\text{-}13$
- missed the math somewhere but doesn't affect result
$\Rightarrow \epsilon_{tot} = \epsilon_{th} + \epsilon_D + \epsilon_{SFP} + \epsilon_{GFP}$
$\epsilon_{tot} = 0.0099 - 0.0099 + 0.0064 + 6.107e\text{-}13$
$\epsilon_{tot} = 0.0064$


3.) Zr Creep?
Givens
$\sigma_m = 200 MPa$
$T = 600 K$
LHR = 150 W/cm
$t = 1.5$ yrs
$n = 5$
$A_0 = 4e-24\ s^{-1}$
$Q = 2.7e5$ J/mol
11/12
$\Rightarrow G = (4.1e10) - (2.3e7)T$ (Pa)
$G = 2.72e4$
$\Rightarrow \dot{\epsilon}_{ss} = A_0 \left(\frac{\sigma_m}{G}\right)^n \exp\left(\frac{-Q}{RT}\right)$
$\dot{\epsilon}_{ss} = (4e-24)\left(\frac{200}{2.72e4}\right)^5 \exp\left(\frac{-2.7e5}{8.314 \cdot 600}\right)$
$\dot{\epsilon}_{ss} = 2.68e-58\ s^{-1}$
↓ math wrong here
$\Rightarrow \dot{\epsilon}_{ir} = C_0 \Phi^{C_1} \sigma_m^{C_2}$
$\Phi = 3e11$ LHR $= 4.5e13$
$\dot{\epsilon}_{ir} = (2.714e-24)(4.5e13)^{0.85}(200)^1$
$\dot{\epsilon}_{ir} = 2.19e-10\ s^{-1}$
$\Rightarrow \dot{\epsilon}_{tot} = \dot{\epsilon}_{ss} + \dot{\epsilon}_{ir}$
$\dot{\epsilon}_{tot} = 2.68e-58 + 2.19e-10$
$\dot{\epsilon}_{tot} = 2.19e-10$
$\epsilon_{tot} = \dot{\epsilon}_{tot}\, t$
$\epsilon_{tot} = (2.19e-10)(4.73e7)$
$\epsilon_{tot} = 0.0104 = 1.04\%$
$A_0 = 4 \times 10^{-24}\ s^{-1}$
not negative exponent
$\dot{\epsilon}_{ir} \approx 1.5 \times 10^{-10}$
- get a lower strain rate to wrong A_0


4.) 1. Soluble Oxides
2. Insoluble Oxides
3. Metals
4. Volatiles
5. Noble Gases
5/5
5.) Microstructure modeling: 6/6
Utilizes material microstructure relationships that are functions of state variables and fuel conditions to determine material properties of fuel and cladding
Has the potential to provide a more predictive fuel performance capability
6.) 1. Low neutron x-section
2. Good thermal conductivity
3. Affordable cost
6/6
7.) Zr diffuses via Soret diffusion up the temperature gradient, and Zr also has different solubilities in U phases, leading to distinct zones of Zr content in radial rings
5/5
8.) MOX has different neutronics, fission gas release, thermal conductivity, etc.
Designed to operate at much higher LHR - higher T - reconstruction
7/8
9.) 1. Corrosive environment
2. Susceptible material
3. Sufficient stress
4. Sufficient time
7/8
Process of PCI involves combination of high internal mechanical stress in the cladding and a corrosive environment resulting from volatile fission products accumulating in fuel-clad gap
- would have liked a bit more
10.) Can occur during LOCA transients
Phase-field modeling being used to account for effects of surface tension and gas bubble pressure
5/6
→ increase bubble P due to ↑ T
11.) RIA - dependent upon control rod insertion/ejection
LOCA - coolant flow reduced or lost altogether
6/8
RIA example - Chernobyl
→ performance differences?
12.) 1. Improved Fuel properties
2. Improved Cladding Properties
Cladding coating/liner
6/6
13.) 1. PCMI
2. Cladding Oxidation and Hydrogen Pickup
4/4