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(4) 5 fission products are:

(1) Oxides — soluble
— Insoluble

Volatile products

Noble gases

Metalic precipitates.

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(5) They provide a relationship between the structure and property of the fuel instead of relating the property of the fuel to a single basic phenomenon such as burn-up. In doing so, such models take into account the fuel performance and safety measures, based on micro structural changes the fuel undergoes.

6/6

Advantage is that they give a better understanding of properties of the fuel overtime, properties such as average grain size of fuel and cladding, defect concentrations, thermal conductivity and corrosion rates.

(6) (1) Zirconium alloy cladding has good anti corrosion properties via the formation of ZrO_2.

(2) It has low neutron-capture cross section.

(3) It is cost effective, ie it is economical interms of it's use as a cladding material — cheap to manufacture and utilize.

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(4) Resistence to void swelling and good themal conductivity.

no oxygen in metallic fuel ~~(2/4)~~ (2/5)

1/5 (7) It undergoes constituent redistribution due to the radial redistribution of ~~oxygen~~ as it migrates down the thermal gradient in the fuel. This makes the fuel composition in the periphery of the fuel close to stoichiometric values at such areas, while the oxygen-metal ratio at the hottest areas (centre) of the fuel reduces.

4/8 (8)

	MOX	LWR
	- Smaller in diameter	Larger diameter of fuel rods
reconstruction	- solid sodium as coolant	Water (liquid) as coolant.
fast reactors	- Very high neutron flux,	Lower neutron flux, less damage to surrounding assembly materials.
high temp.		
	- Very high burnup, twice LWR	Lower Burn up levels attainment.

8/8 (9) S. T. E. M.

(1) Suitable material ie material can undergo corrosion; All Zr alloy claddings are susceptible to corrosion from fission products

(2) Adequate amount of time for process to occur → Development of corrosive environment, initiation of SCC, propagation of SCC and ultimately failure. Time is ultimately related to burn-up.

(3) Corrosive environment must be present → formation of corrosive species such as Caesium-Iodide results in PCI, as they attack the cladding

(4) Sufficient stress must be present for phenomenon to occur: stress can/is imposed on cladding internally from fuel and externally by coolant, resulting in creep

4/6 (10) High Burn up Structure is xterized by very high porosity which greatly reduces thermal conductivity of the area/region by the retention of fission gases. The increased heat accumulation in the area due to low heat dissipation accounts for possible oxide fuel fragmentation.

→ ↑ T during transients increases P inside bubbles → fracture

(11)

RIA	LOCA
Drop/ Ejection of control rod occurs	Coolant is lost or reduced
~~Drop~~ Rapid rise in fuel power and temperature due to drop is 1° mechanism of action	Cladding burst from ballooning out due to pressure drop is 1° mechanism of action.
Affected by temperature and density of coolant.	Affected 1°ly by nature of cladding in regards to levels of oxidation and hydride embrittlement.

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- Example of RIA is Chernobyl RIA.

(12) (a) Mitigation through fuel and cladding design → To increase time for water to boil, fuel to melt, and breach of primary pressure boundary

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(b) Mitigation through changes in nuclear reactor operations. X

(c) An option being explored is use or development of UO_x dopants and alternate claddings eg sillicon Carbid

- got Safety + ATF concepts mixed here

(13) (1) Pellet-clad Mechanical Interaction: Total permanent hoop strain is limited to about 1%, throughout fuel lifetime.

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(2) cladding wear: Maximum cladding wall thickness reduction is 10%.

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(3) (a) Thermal creep rate — what eqn is this?

$$3.14\times10^{24}\times\left(\frac{200}{(4.2519\times10^{10}-2.2185\times10^{7}\times600)}\right)^{5}\times e^{\left(-2.7\times10^{5}/8.3144598\times600\right)}$$

$\Rightarrow 7.699\times10^{-11}$

— looks right, but wrong value...

(b) Irradiation creep rate

$$3.557\times10^{-24}\times\left(150\times3\times10^{11}\right)^{0.85}\times200^{1}$$

✓ ✓ $\Rightarrow 2.8664\times10^{-10}$

Total creep rate $= 7.699\times10^{-11} + 2.8664\times10^{-10}$ ✓

$\Rightarrow 3.6363\times10^{-10}$

After ~~8~~ 1.5 years $= 3.6363\times10^{-10}\times3600\times24\times365\times1.5 = 1.7\%$ or 0.0172 // Ans. ✓

(a)

(1) (a) $t^{*} = 6.62\times10^{-7}\exp\frac{11949}{625}$

$\Rightarrow$ 133 days. ✓

(b) $\delta^{*} = \cancel{6.62\times10^{-7}\exp{11949}/625}$

$= 5.1\exp^{-550/625}$

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$\Rightarrow 2.1153$ ✓

extra zero here made value very small

(c) $7.48\times10^{6}\exp\frac{-125000}{625}(400-133) + 2.1153$ $\quad K_L \sim 0.0154$

$\Rightarrow 1.035\times10^{-80} + 2.1153$

$\Rightarrow 2.1153$ Microns // Ans. $\quad \delta = 6.23\,\mu m$

Should know this doesn't make sense

(b) $$\frac{m_H}{m_{Zr}} = \frac{2f \times \delta \times \rho_{oxide} \times f^{0}_{ZrO_2} \times M_H / M_O}{t - \frac{\delta}{PBR} \times \rho_{metal}} \times 10^6$$ ✓

$$f_{ZrO_2} = \frac{32}{91+32} = 0.26$$

5/8

?

$$= \frac{2 \times 0.18 \times 2.1153 \times 5.68 \times \cancel{1.47} \times \frac{1.00794}{16}}{\left(500 - \frac{2.1153}{1.56}\right) \times 6.5} \left[\times 10^6\right]$$

$\Rightarrow$ ~~1.5406 × 10^-4~~ 0.41 $\Rightarrow 1.2358 \times 10^{-4}$ // Ans. + units?

(2) 0/16