(1) Joy (7)

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(a) $T = 625\,K$ $t = 400$ days

initial wall thickness $500\ \mu m$

12/18

$\delta = 500 \times 10^{-4} = ?$

$\delta = \delta^* + K_b(t - t^*)$

$t^* = 6.62 \times 10^{-7} \exp\left(\frac{11949}{T}\right)$

$t^* = 6.62 \times 10^{-7} \exp\left(\frac{11949}{625}\right) = ?$

$K_b = 7.48 \times 10^{6} \exp\left(\frac{-12500}{625}\right) = ?$

~~$t^* = 6.62 \times 10^{-7} \exp$~~

My Calculator is malfunctioning

The value gotten for t^* and K_b together with δ^* which is $= 5.1 \times \exp\left(\frac{-550}{625}\right) = ?$

will be added in the main formular

$\delta = \delta^* + K_b(t - t^*) = ?$ The answer for the oxide thickness

(b) $PBR = 1.56$ $\rho_{Zr} = 6.5$ g/cc

$\rho_{ZrO_2} = 5.68$ g/cc

$f = 0.18$

on the right track... but I need numbers to see if you would actually do things correctly

$$C_H(\text{wt. ppm}) = \frac{2 f \delta \rho_{ZrO_2} f^{\circ}_{ZrO_2} \frac{M_H}{M_O}}{(t - \delta/PBR)\rho_{Zr}}$$

where $f^{\circ}_{ZrO_2} = \frac{32}{91+32}$

$C_H(\text{wt. ppm}) = 2 \times 0.18 \times \delta \times 5.68 \times \frac{32}{91+32} \times \frac{1}{}$ Because I do have Calculator

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(3) 4/4

Pilling-Bedworth ratio — Is the ratio of volume per unit of metal oxide to the volume per unit of the corresponding metal

PBR < 1 — oxide coating layer is thin and provide no protective effect

PBR > 2 — Oxide Coating layer ~~is thick~~ Chips off and no protective effect

1 < PBR < 2 — Oxide Coating Passivating and provides a protecting effect.

(4) 12/14

~~Hydrides~~ Hydrogen pickup causes hydrogen embrittlement, loss of fracture toughness, Delayed hydride Cracking, accelerated Corrosion and accelerated irradiation growth. Hydride concentration ~~are~~ not uniform because they respond to Temperature and stress gradient

Hydrides effect: Embrittlement, ~~less~~ reduced Ductility, ~~Cladding fail~~ etc

DElayed hydride cracking is a phenomenon based upon increase solubility of Hydrogen in high tensile stress around a crack tip - so where do they form?

(5) 10/14 (2)

RIA is a Reactivity initiated Accident which is one of the Design Base Accident that is used to establish Design and define safety limit and margins

RIA-~~B~~WR : Control Rod Ejection Accident (CREA) ~~this~~ — This is when Control rod is ejected totally from the Core due to mechanical failure and when this happens, reactivity increases and it occurs within 0.1S, at normal Coolant Temperature and pressure but with nearly zero reactor power

RIA-BWR : Control Rod Drop Accident which occurs at coolant close to room temperature and atmospheric pressure and at nearly zero power.

Other RIA includes inadvertent changes in coolant temp and void fraction.

RIA leads to rise in power and temperature and the power ramp leads to failure of fuel rods etc

- needed more here. how does the material behave?

(6) 10/14

LOCA is loss of coolant accident, it occurs over a time scale of minutes longer than RIA

Here, coolant flow is reduced or lost altogether.

When LOCA occurs, pressure drops, engaging emergency shutdown system ~~and~~ SCRAMS the reactor stopping the fission chain reaction, and the reactor water ~~get~~ gets expelled into the containment while ECCS begins to remove heat.

-needed more...

(7) 5/5

At high burnup, ductility of cladding is significantly reduced due to existing corrosion, hydrogen embrittlement and irradiation hardening ~~are~~ observed

For RIA cladding failure occurs at lower enthalpy increases for irradiated than for fresh fuel rods, thus, the susceptibility to failure increases with increasing fuel burnup.

(8) 8/8 (4)

Four pathways to make the fuel|cladding system more accident tolerant are:

1. Improved reaction kinetics with steam:
   - reduced heat of oxidation
   - lower oxidation rate
   - reduction of hydrogen production
2. Improved fuel properties:
   - lower fuel operating temperature
   - minimized cladding internal oxidation
   - Higher fuel melt temperature
3. Improved Clad properties
   - Resilience to clad fracture
   - Thermal shock resistance
   - higher cladding melt temperature
4. Enhanced fission product retention:
   - Retention of gaseous fission products
   - Retention of solid|liquid fission products

One of the ATF option being considered is the use of FeCrAl to improve oxidation resistance and the reason is because FeCrAl forms Al_2O_3 ~~which~~ and it enhances stability than ZrO_3, FeO_2 and Cr_2O_3

(9) 5/6 (5)

Alpha Zirconium during high Temperature phase can phase trasform to betal Zirconium at 863°C
With high O content - beta phase matrix with oxygen stabilized alpha Zirconium closest to the oxide|metal interface.
Stabilized alpha causes ~~brittleness~~ brittle failure behavior

- high rates of corrosion, breakaway ...

~~3 examples of limiting~~ ^ few (10) 6/6

3 examples of limiting phenomena governing LWR operation

① PCMI - complex process with maximum risk for failure when the fuel pellet to cladding gap closes firmly and reactivity of a fuel is still high

② Cladding oxidation and hydrogen pickup - for ZrO_2 formation at cladding water side surface, a typical criterion is related to the ASTM criterion of a max cladding wall thickness reduction of 10%

③ DNB: Ratio of the heat flux ~~of a fuel rod~~ rate needed to cause DNB at a given local coolant properties to the actual local heat flux of a fuel rod ie DNBR

(11) 5/6 (6)

CRUD deposit accumulates on Ni alloy and Stanless Steel surfaces - degrading heat production by nuclear fuel because it is slowly eroded by circulation of hot pressurized water

∴ CRUD deposition on cladding surface can reduce heat transfer, increasing fuel temperature also increases oxidation rate

Safety:
- source term of activation products

(12) 4/4

Two water Chemistry Control:

① Use of lithium oxide to contro PH
② Zinc injection to reduce radiation fields

(2) 4/4

rate - limiting step in the aqeous corrosion of Zr cladding is the transport of O species to the oxide layer