

①

[97]

At first let's check if the transition has occurred or not.

20/02

$$t^*(\text{d}) = 6.62 \times 10^{-7} e^{\frac{-11949}{625}} / \quad T = 625 \\ = 133.006 \approx 133 \text{ days}$$

So as transition has occurred we use the linear rate eqn.

$$\therefore \delta^*(\text{um}) = 5.1 e^{-\frac{550}{T}} \\ = 5.1 e^{-\frac{550}{625}} \\ = 2.13 \text{ um}$$

$$\therefore k_L = 7.48 \times 10^6 e^{-\frac{12560}{625}} \\ = 0.015417$$

$$\therefore \delta(\text{um}) = \delta^* + k_L (t - t^*) \\ = 2.13 + 0.015417 (400 - 133.006) \\ = \boxed{6.25} \text{ um Ans}$$

(b) For one year we have the oxide thickness as follows

$$\delta(\text{um}) = \delta^* + k_L (t - t^*) \\ = 2.13 + 0.015417 (365 - 133.006) \\ = \boxed{5.71 \text{ um}}$$

(2)

Given, $P_{\text{BR}} = 1.56$, $\rho_{\text{Zn}} = 6.5 \text{ g/cc}$, $\rho_{\text{ZnO}_2} = 5.68 \text{ g/cc}$

\therefore Hydrogen pickup by the cladding

$$c_{\text{H}}^{\text{clad}} [\text{wt. ppm}] = \frac{2f \times \delta \times \rho_{\text{ZnO}_2} \times f_{\text{ZnO}_2}^{\circ} \times \frac{M_{\text{H}}}{M_{\text{O}}}}{(t - \frac{\delta}{P_{\text{BR}}}) \times \rho_{\text{Zn}}} \times 10^6 \quad \text{--- (1)}$$

We have,

$$f_{\text{ZnO}_2}^{\circ} = \frac{32}{91+32} = 0.26$$

$$M_{\text{O}} = 16, M_{\text{H}} = 1$$

$$f = 0.18, t = 500 \mu\text{m}$$

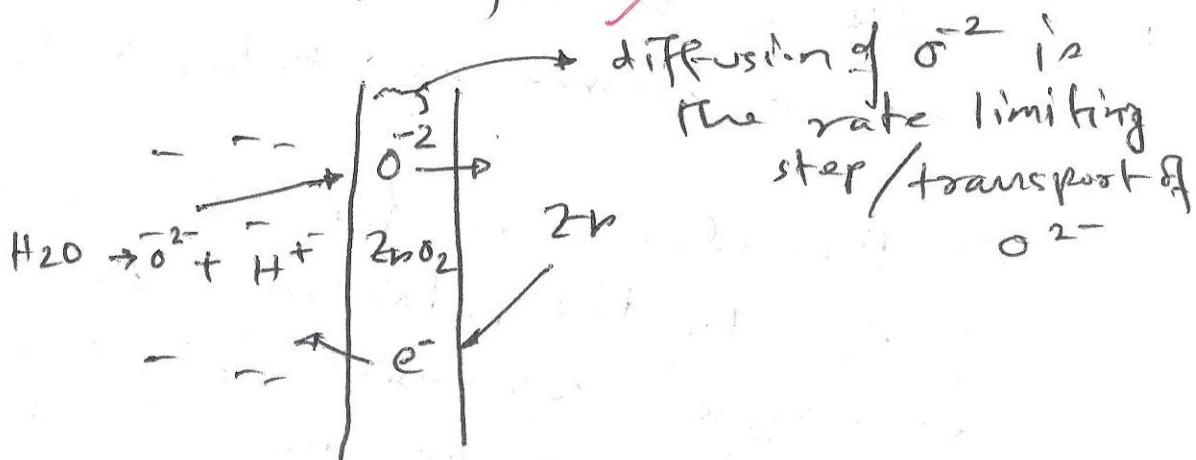
\therefore From (1) we have

$$c_{\text{H}}^{\text{clad}} [\text{wt. ppm}] = \frac{2 \times 0.18 \times 5.71 \times 5.68 \times 0.26 \times \frac{1}{16}}{(500 - \frac{5.71}{1.56}) \times 6.5} \times 10^6$$

$$= \underline{58.81} [\text{wt. ppm}] \text{ Ans}$$

(3)

② The rate limiting step ~~is~~ in the aqueous corrosion of Zn ~~cladding~~ is the diffusion of charged oxygen species (O^{2-} ~~car~~) through the initial protective ~~ZnO₂ formed~~ layer to reach Zn for further reaction.



③ PBR is defined as the ratio oxide volume to the metal volume

$$PBR = \frac{\text{Volume}}{\text{Metal}} = \frac{\text{Oxide} \times \text{Metal}}{\text{Metal} \times \text{Oxide}}$$

It tells us how much metal has undergone corrosion tells us about the nature of the oxide forming
if $PBR < 1$ then thin layer does not provide passivating protection

If $PBR > 2$ → thick layer ~~chip~~ chips off offers no protection

$1 < PBR < 2$ → provides passivating protection through the formed oxide layer.

(4)

aster

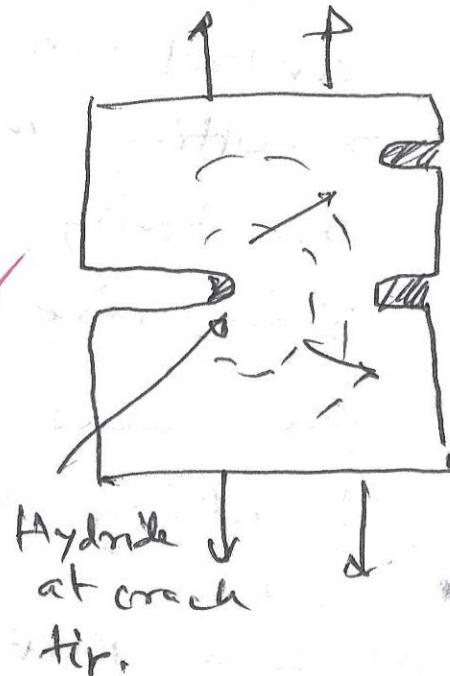
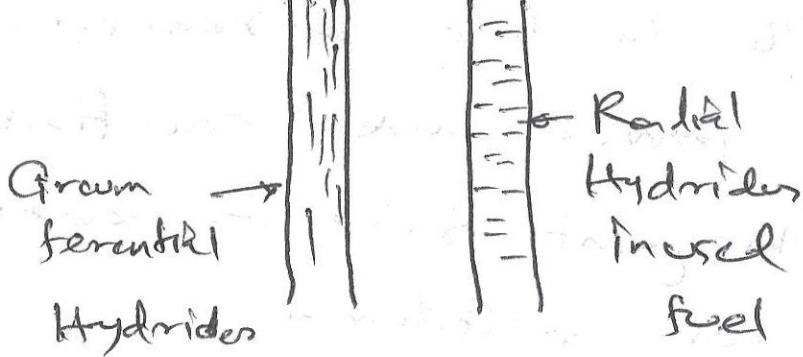
17/2

- Hydrides usually forms towards the rim of the cladding but it can have a depth of 50 - 60 microns. They can also form at the crack tips, a phenomenon known as Delayed Hydride Cracking.

Hydrides are formed by the absorption of H₂ by the cladding. As the cladding undergoes corrosion at the waterside the water breaks down and forms excess hydrogen. The more the oxidation, the more the H₂ production. These H₂ is picked up by the cladding. However H₂ has very low solubility in the Zn. As a result Hydrides are formed. The H₂ or hydrides move down the lower thermal gradient or low temperature. But why?
Hydrides are formed towards the rim. Hydrides also moves towards the tensile stress. During the life

of the fuel inside the reactor
the hydrides forms circumferentially.
However, soon after in the dried up
used fuel hydrides rearrange them
self ^{rearrange} radially due to radial tensile
stress.

At the crack tip the hydrides from
the bulk moves to the crack tip due
to the difference between the chemical
potential caused by the solubility of
hydrides resulting from hydrostatic
tensile stress.



② Facts:

- ① Hydrides causes embrittlement
- ② They are brittle in nature and

(6) lowers the ductility

- ③ causes delayed hydride cracking
- ④ In dried fuel causes more radial cracks.

⑤ leads to fuel, zirconia cracking and interaction of fuel, fission products ~~and~~ with ~~coolant~~ coolant.

(5)

18/12

⑥ RIA: RIA is an reactivity Insertion Accident which occurs by the inadvertent release ejection / drop of control rod in the PWR / BWR and resulting in a prompt increase of reactivity within the reactor. This rise in power and reactivity can cause subsequent rise in power leading to core meltdown.

→ possibly, not always

⑦ In a PWR or BWR a typical RIA is caused by Control Rod Ejection Accident (CREA) or, Control Rod Drop Accident (CRDA).

This is caused by the failure of control rod mechanism or housing and the rod is ejected in part due to coolant pressure or drops in BTR due to gravity. This causes a prompt surge of reactivity and power due to increase fission. The reactor becomes supercritical leading to core meltdown in worst cases.

Q1. During the RIA, the fuel temperature rises drastically leading to solid thermal expansion and accumulated fission gas.

2. Fission gas expansion can lead to FGR and GB separation causing rod internal pressure to rise leading to ballooning/bursting and fuel fragmentation.

3. On the other hand the solid thermal expansion can lead to PCMF and PCMI leading causing.

incipient cracking in cladding periphery. This can lead to hydride assisted PCMI failure in post DNB cases. During DNB can cause burn out or post DNB can cause fuel fragmentation.

- 8/0
- ⑥ LOCA - loss of Coolant Accident is the design Basis accident which happens when the primary coolant flow to the core is disrupted, leading to the rise of temperature.
 - ⑦ It's difference with RIA is given below.

LOCA	RIA
<p>① Primary Coolant flow is lost and ECCS will be triggered as emergency safety mechanism kicks in</p>	<p>① Control rod withdrawal is / dropped ready to excess reactivity insertion</p>

<u>LOCA</u>	<u>RIA</u>
② Temperature rises due to lack of coolant ✓	① Temperature rises due to excessive fission from excess reactivity initially.
③ No excess reactivity is found, at least initially due to negative feedback effect	② Excess reactivity is found from get go. ✓
④ Excess temperature causes excess oxidation and hydrogen pickup and the fuel cladding becomes embrittled - meat during quenching - slow, more time for oxidation, hydrogen, plastic deformation	⑤ Fuel failure due to excessive net internal pressure or thermal expansion in most cases.

(7) Two Pathways:

- ① Improved fuel design; FP retention
 - Ⓐ improved solid FP retention
 - Ⓑ improved gaseous FP retention
- ② Improved reaction kinetics with steam for cladding.
 - Ⓐ low heat of oxidation
 - Ⓑ low hydrogen pickup
 - Ⓒ low oxidation
 - Ⓓ low corrosion

ATF option: Fe-Gp-Al \rightarrow forms protective Al_2O_3 layer that protects the cladding from excess corrosion and ~~oxy~~ oxidation.

- (8) At high temperature the Zr cladding undergoes more oxidation. The protective layer chips off and causes runaway or breakaway oxidation (at shear rate). More oxidation causes

(11)

✓ in turn

more hydrogen release, causing more
hydrogen pick up and ✓ embrittlement
- from transmutation, leading to embrittlement

(9)

- Liners can be used to protect
improve steam oxidation resistance
in LWR cladding.
Liners option: Ti_2Si_2C , Cr etc.
- coating, not liner
- liner would be on the outside*

(10) Cladding elongation and Assembly

boor

- ① The anisotropic nature
and irradiation growth
causes cladding elongation
② This causes the assembly
of boor and blockage of
coolant.

③ Cladding wear

- ① Cladding's gets weared down
due to hot coolant flow
- ② Max limit < 10% of cladd thickness

(3)

PCMI

(12)

Limit on PCMF is hoop strain less than 4%.

(11)

CRUD is known as Chalk River Unidentified Deposition. It is mostly composed of Ni, Co and Fe.

Performance & Safety Impacts

4%

① Causes degradation of fuel - doesn't contact fuel, in outside of cladding

② Blocks coolant flow
- yes, but very minor

③ Produces activated Co^{60} which can flow out and cause radiation leak issue.

(15)

5%

① H_2 overpressure: To maintain $\text{pH} > 6.9$

- H_2 controls redox potential, lower pH
- LiOH increases

② Zinc injection: to keep Co^{60} more in coolant for filtering.

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Mox

CMP

7/9

- ① Smaller diameter
- ② Smaller length
- ③ Higher Burnup ✓
- ④ Large gas plenum
- ⑤ Higher friction product production
- ⑥ Can be operated at higher burnup

⇒ physical phenomena?

- restructuring, SSG, etc.

