

Chapter 15 Fission Gas Release

Once gas is released;

- it does not diffuse back into the solid
- it does not slow the diffusion out of the solid
- the gas pressure can cause sintering

$T < 1300 \text{ }^\circ\text{K}$	<i>gas atoms "frozen"</i>
$1300 < T < 1900 \text{ }^\circ\text{K}$	<i>diffusion release</i>
$1900 < T \text{ }^\circ\text{K}$	<i>bubble release</i>

15.2 Experimental Techniques - Read

15.3 Recoil & Knockout

figure 15.7, Table 15.1

P_i rate of generation of recoils of species i per unit volume at a distance x from the surface.

q_i rate at which particles of species i are stopped in a unit volume of solid at a distance x from the surface.

I_i rate at which recoil of species i cross a unit area of surface.

$$q_i = \frac{1}{2} \left(1 + \frac{x}{\mu} \right) P_i \quad \text{for } x \neq 0$$

$$q_i = P_i \quad \text{for } x = 0$$

$$I_i = \frac{P_i \mu}{4} \quad \text{Not simple!}$$

15.3.1 Direct Recoil - Read

$$\frac{dC_i}{dt} = \frac{1}{2} Y_i \dot{F} \left(1 + \frac{x}{\mu_{ff}} \right) - \lambda_i C_i \quad \text{for } x \neq 0$$

$$\frac{dC_i}{dt} = Y_i \dot{F} - \lambda_i C_i \quad \text{for } x = 0$$

$$I_i^{rec} = \frac{Y_i \dot{F} \mu_{ff}}{4} \quad \text{See Fig 15.11}$$

15.3.2 Knockout of Matrix Atoms - Read

$$I_{ff}^{rec} = \frac{1}{4} 2 \dot{F} \mu_{ff}$$

15.3.3 FP Release by the Knockout Mechanism - Read

15.3.4 Short Lived Fission Products - Read

$$q_i^{ff} + q_i^{KO} = P_i + \lambda_i C_i$$

Stopping
of FF

Knock
in

Knock
out

Decay

15.3.5 Release of Short Lived Isotopes Due to Surface Fissions - Read

15.3.6 Stable Fission Products - Read

15.4 Equivalent Sphere Model of Diffusional Release

- 1.) Simple Diffusion
 - 2.) Effect of Trapping
 - 3.) Resolutioning
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15.5 Simple Diffusion

15.5.1 Post irradiation Annealing

(assume Kr Xe)

$$\frac{C}{t} = D \frac{1}{r^2} \frac{r^2 C}{r} \quad \text{Fick's Law}$$

$$f = \frac{6}{\sqrt{a}} \sqrt{\frac{Dt}{a^2}} \quad \text{a radius of grain}$$

fractional
release

$$f = \frac{6}{\sqrt{a}} \sqrt{D' t}$$

15.5.2 In Pile Gas Release

$$\frac{C}{t} = Y \dot{F} + D \frac{1}{r^2} \frac{r^2 C}{r} - C$$

$$f = 4 \sqrt{\overline{D'} t} \quad \text{for } f < 0.3$$

15.5.3 Fission Gas Release in a Fuel Element

$$\overline{f} = 3 \sqrt{\overline{D'}}$$

\overline{D} is empirical diffusion coefficient averaged over radius and length (Figure 15.16)

15.6 Diffusion With Trapping

Figure 15.17

1.) Natural Defects

- a.) Grain boundaries Figure 15.19
- b.) Dislocation lines
- c.) Closed pores in as - fabricated fuel
- d.) Impurities in solid

2.) Radiation Produced Defects

- a.) Vacancy Clusters
- b.) Interstitial loops
- c.) Fission gas bubbles
- d.) Solid fission product precipitates

15.7 Gas Accumulation in Grain Boundary Bubbles

Speight model(Fig. 15.22 a&b)

Tries to determine how much gas is ;

- a.) in grain bubbles***
- b.) in grain solution***
- c.) in between GB's***

Full expression is in eq. 15.179

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with substantial resolutioning

$$f_{gb} = 3 \frac{D}{a^2 b} \frac{a}{\mu_{Xe}^{KO}} \quad (15.182)$$

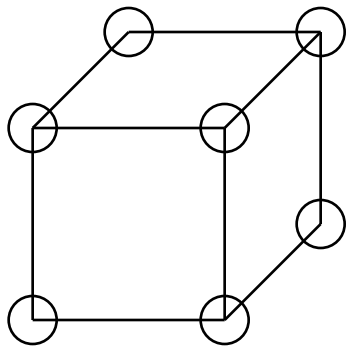
<i>Apparent diffusion coefficient</i>	<i>radius of equivalent sphere</i>	<i>Resolution coefficient</i>	<i>Range of Knock on in fuel</i>
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This model is not too useful because it only treats grain boundaries in tact.

15.8 Breakaway Gas Release Due to Bubble Interconnection

15.8.1 Intragranular Bubbles

Set up unit cell to figure when bubbles touch



**contributes
GB bubbles)**

**Each bubble
 $\frac{1}{8}$ to cube (No**

Critical Porosity for $= \frac{R^3}{\text{crit}} = \frac{4 R^3}{3 (2R)^3}$

Breakaway porosity $= \frac{1}{6} = 52\%$ $\frac{V}{V} = \frac{\frac{R^3}{6}}{1 - \frac{R^3}{6}} = 110\%$

However, breakaway swelling would occur at an even earlier value because of random distribution of bubbles.

15.8.2 Grain Boundary Bubbles

Use same approach as earlier but set up equivalent circles on grain boundary, subject to

$$\left(\frac{2}{gb} \right) N_{gb} = 1$$

gb = radius of circle containing one bubble

R_{gb} = radius of bubble

If we use a cubic array on the surface;

$$\frac{R_{gb}^2}{R_{gb, crit}^2} = \frac{1}{4} \quad \text{This is } > 75\% \text{ of surface}$$

and corresponds to 46 % of V_0

Point of previous comparison is that breakaway swelling value is lower for grain boundaries than for the bulk.

Next question is how do bubbles get to grain boundaries ?
