

Chapter 14 Pore Migration and Fuel Restructuring Kinetics

Major Differences Between Pores and Bubbles

| <u>Parameter</u> | <u>Pores</u> | <u>Bubbles</u> |
|---------------------------|-------------------------------|------------------------------------|
| Size | Large, >1 mm | Small 0.01 mm |
| Gas | He, CO, CO₂ | Fission Gases |
| Gas Pressure | Low, Few Atm. | High, 100's ATM. |
| Densification | Important | Not Applicable |
| Shape | Lenticular | Spherical |
| Movement Diffusion | Vapor Transport | Surface or Volume Diffusion |

Bubble Migration

| | |
|--------------------------|-----------------|
| Surface Diffusion | 1/R |
| Volume Diffusion | constant |

Pore Migration

Vapor Transport a R (mech. equilibrium.)
See Figures 14.1, 14.2



Fig. 14.1 Lenticular pores migrating up the temperature gradient in UO_2 . The temperature increases from bottom to top. (Courtesy of J. R. MacEwan and V. B. Lawson, Atomic Energy of Canada, Ltd.)

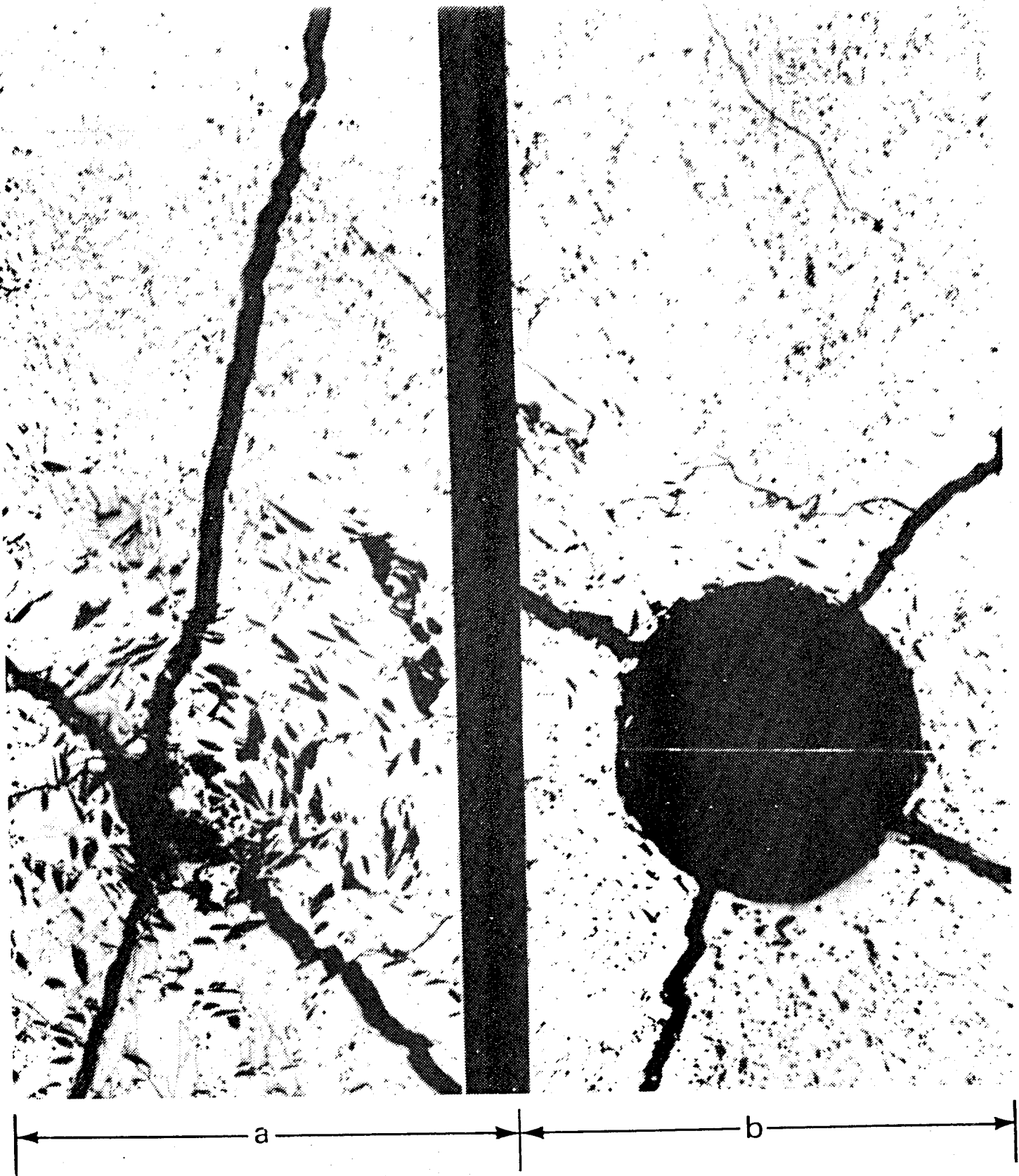


Fig. 14.2 Section through an irradiated fuel pin. (a) Lenticular pores clustering about the fuel center. (b) After agglomeration of the pores to form a central void. [From P. F. Sens, *J. Nucl. Mater.*, 43: 293 (1972).]

14.2 Pore Migration by Vapor Transport

Figure 14.5

Set heat transfer parameters equal

$$k_p \frac{dT}{dx} = k_s \frac{dT}{dx}$$

and $\frac{k_s}{k_p} = 5$

Note ; $v_p = J$

$$J = \frac{D_g}{kT} [P^\circ(x + \Delta x) - P(x)]$$

$$\frac{dP^\circ}{dT} = \frac{dT}{dx} \frac{dP}{dx}$$

Diff. Coeff. for matrix molecules in gas

$$D_g = \frac{\text{Const.} \cdot T^{\frac{3}{2}}}{12 \cdot D_P} \sqrt{\frac{M_1 + M_2}{M_1 M_2}}$$

Collision diam. for 2 species in gas

Parameter from theory

$$\frac{kT}{12}$$

12

Force constant

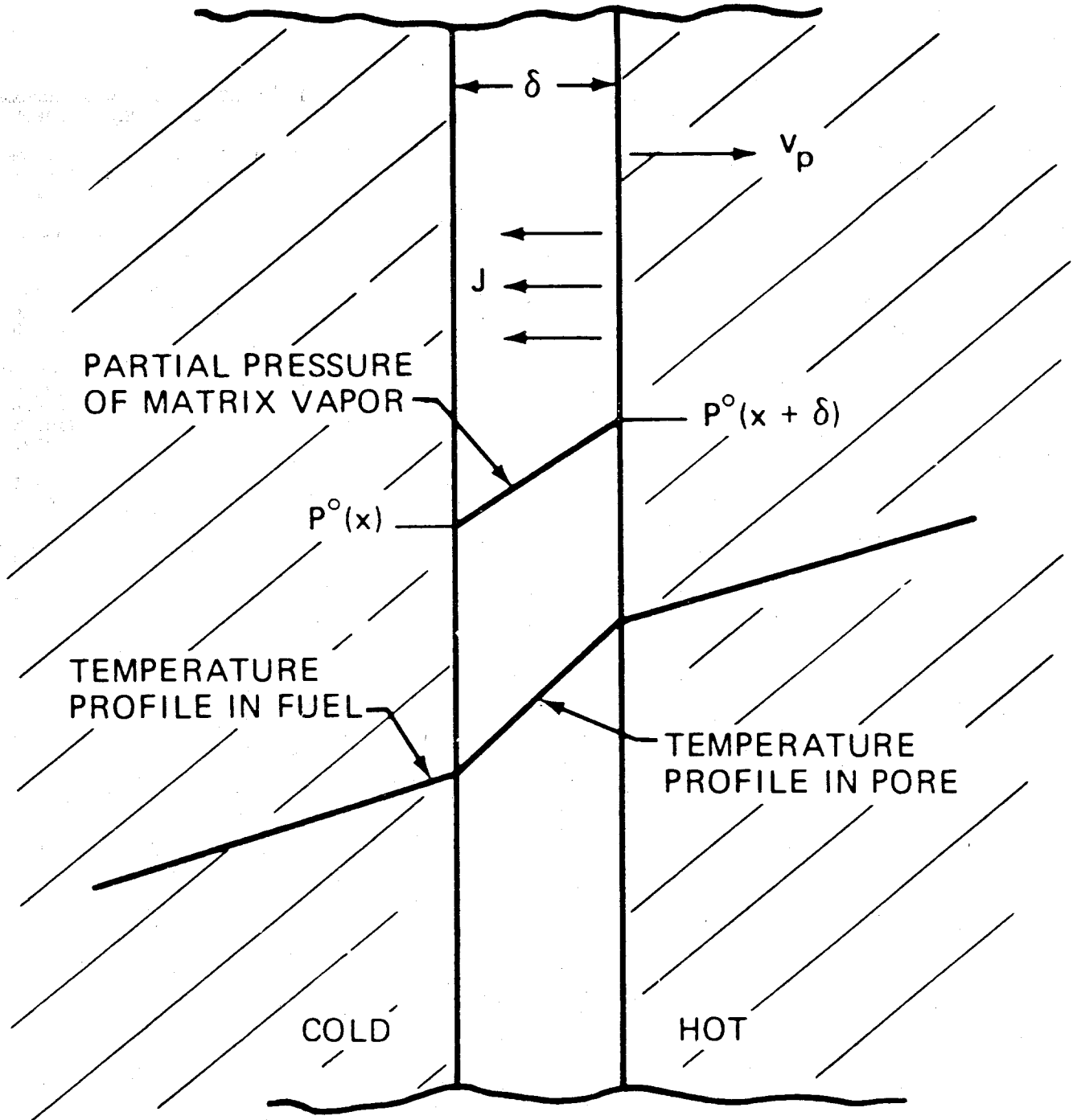


Fig. 14.5 A lenticular pore in a solid containing a temperature gradient. The pore is assumed to be infinite in extent in directions perpendicular to the temperature gradient.

Two things to consider;

1.) Impurities (Fig. 14.6)

They depress vapor pressure on the hot side.

2.) Cold Side Condensation Limitations

Increases vapor pressure

14.3 Porosity Redistribution Kinetics

**Read section for model description
(Figures 14.8, 14.9)**

14.4 Columnar Grain Growth

Using the approach by Nicols, get pore velocity as a function of fuel radius. See figure 14.10.

Define d = distance a pore at outer edge of columnar zone moves into zone.

$$t = - \frac{r_1^{-d}}{r_1} \frac{dr}{v_p(r)} = - \frac{T_1^d}{T_1} \frac{dT}{v_p \frac{dT}{dr}}$$

outside of columnar grain region

Rest of section involved with above equations for t with appropriate values of v_p

Problem: Define the fractional radius of central void in terms of initial porosity

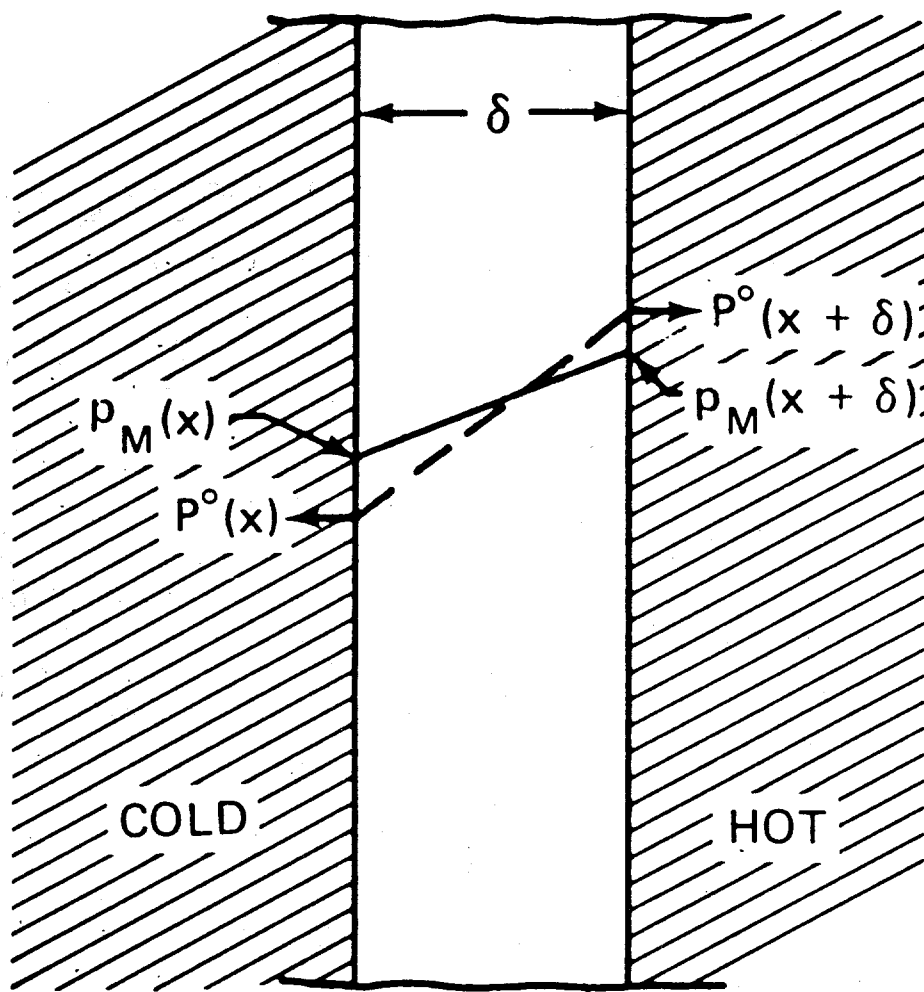


Fig. 14.6 Partial-pressure profiles of matrix solid across a particular pore, showing the effects of impurity accumulation on the hot face and condensation rate kinetics on the cold face. - - -, partial pressure of matrix material in ideal pore. —, partial pressure of matrix material in actual pore.

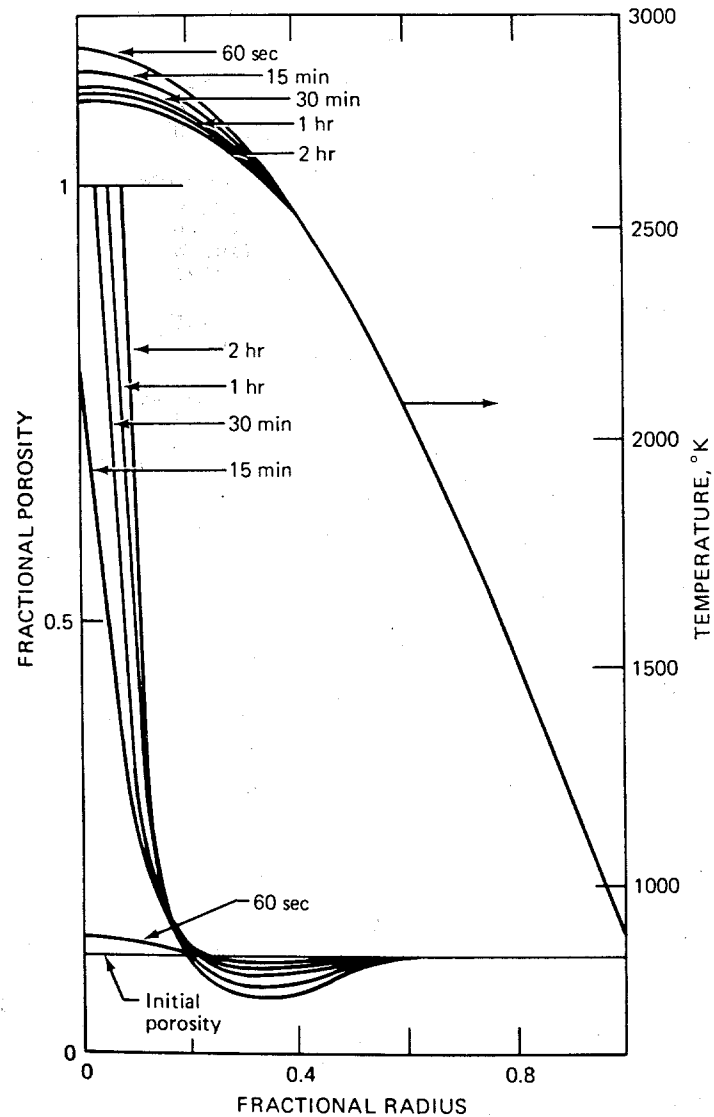


Fig. 14.8 Calculated temperature and porosity distributions at different times from the start of irradiation. Fuel radius = 0.5 cm. Linear power = 600 W/cm. (Based on Ref. 1.)

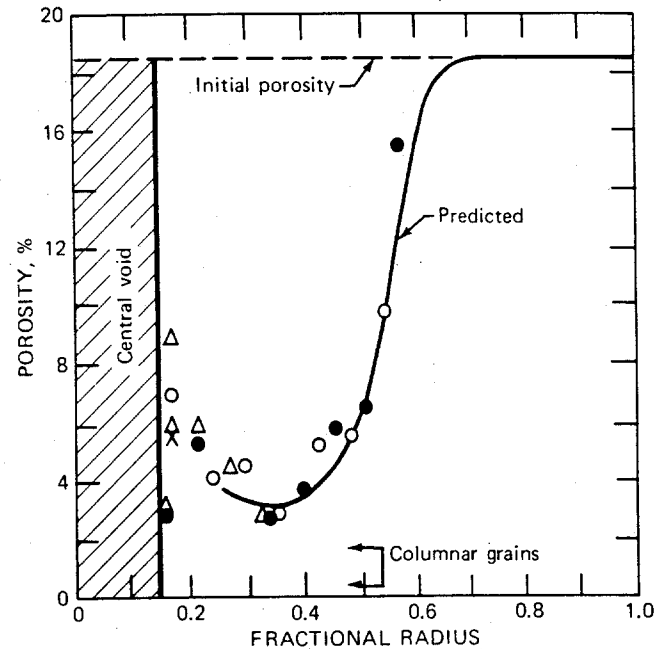


Fig. 14.9 Comparison of experimental and predicted porosity distributions in a fuel rod operated at a linear power of 450 W/cm at a burnup of 0.7%. The fuel rod was fabricated by vibratory compaction of $(U,Pu)O_2$ microspheres. [After W. J. Lackey, F. J. Homan, and A. R. Olsen, *Nucl. Technol.*, 16: 120 (1972).]

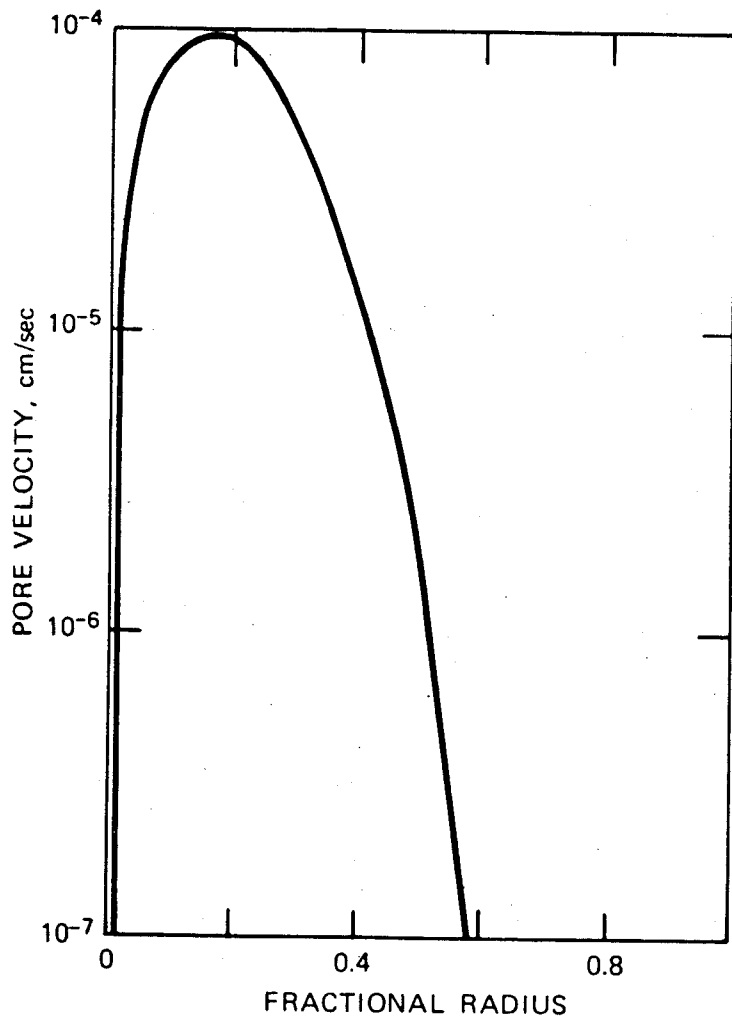
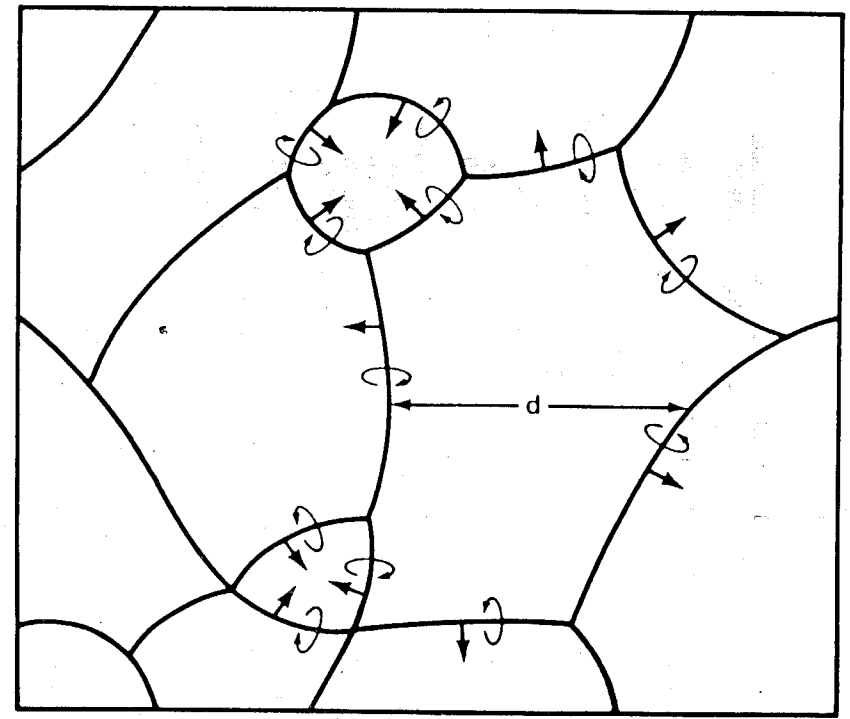


Fig. 14.10 Migration velocity of the lenticular pores at the start of irradiation in the fuel rod described in Fig. 14.8. No restructuring has occurred yet.





 DIRECTION OF GRAIN-BOUNDARY MOTION
 DIRECTION OF NET ATOM MOVEMENT

Fig. 14.12 Grain-boundary motion during grain growth (d = grain size).

14.5 Equiaxed Grain Growth Region

- **Curved grain boundaries cause large grains to grow at the expense of small grains**

Figure 14.12

Atoms like to be on the concave side instead of convex side because they are surrounded by more matrix atoms

• **Kinetics**

$$d^m - d_o^m = k_o t \exp - \frac{Q}{kT}$$

$$d^2 - d_o^2 = k_o t^a \exp - \frac{Q'}{kT}$$