Final Class Review

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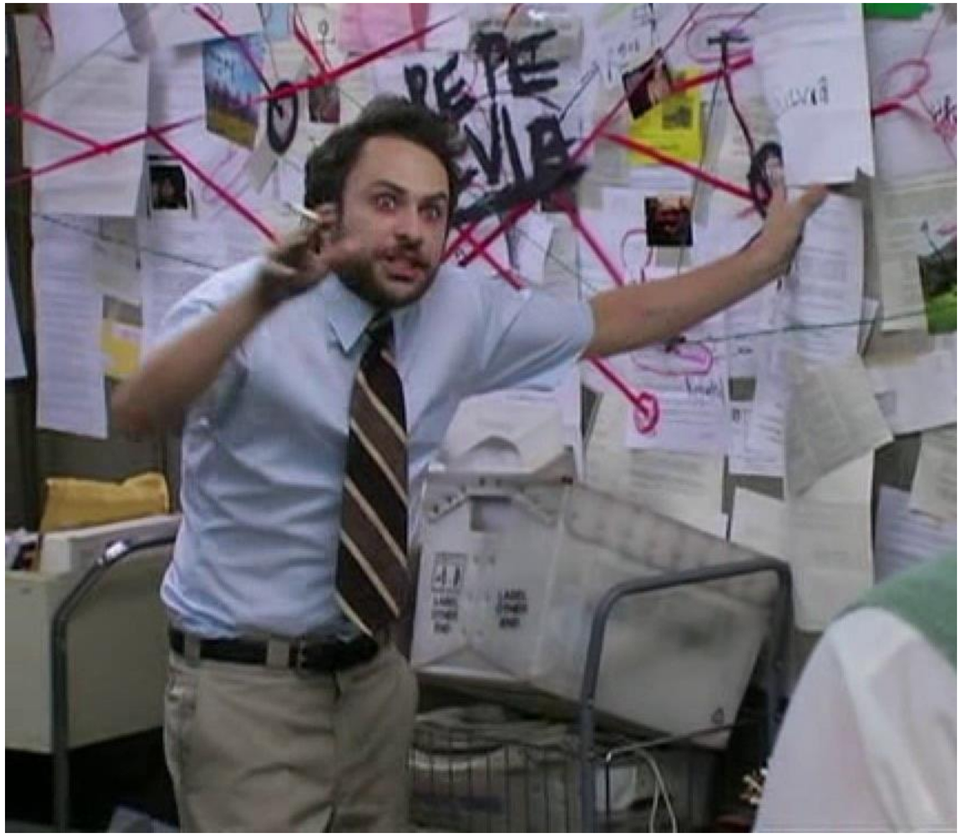
Final Exam Structure

- We will follow a similar format to the mid-term:
  - Non-cumulative (but you need your knowledge from before the mid-term)

12/15 (Monday) from 10:30 am – 12:30 pm in Cooley 2918



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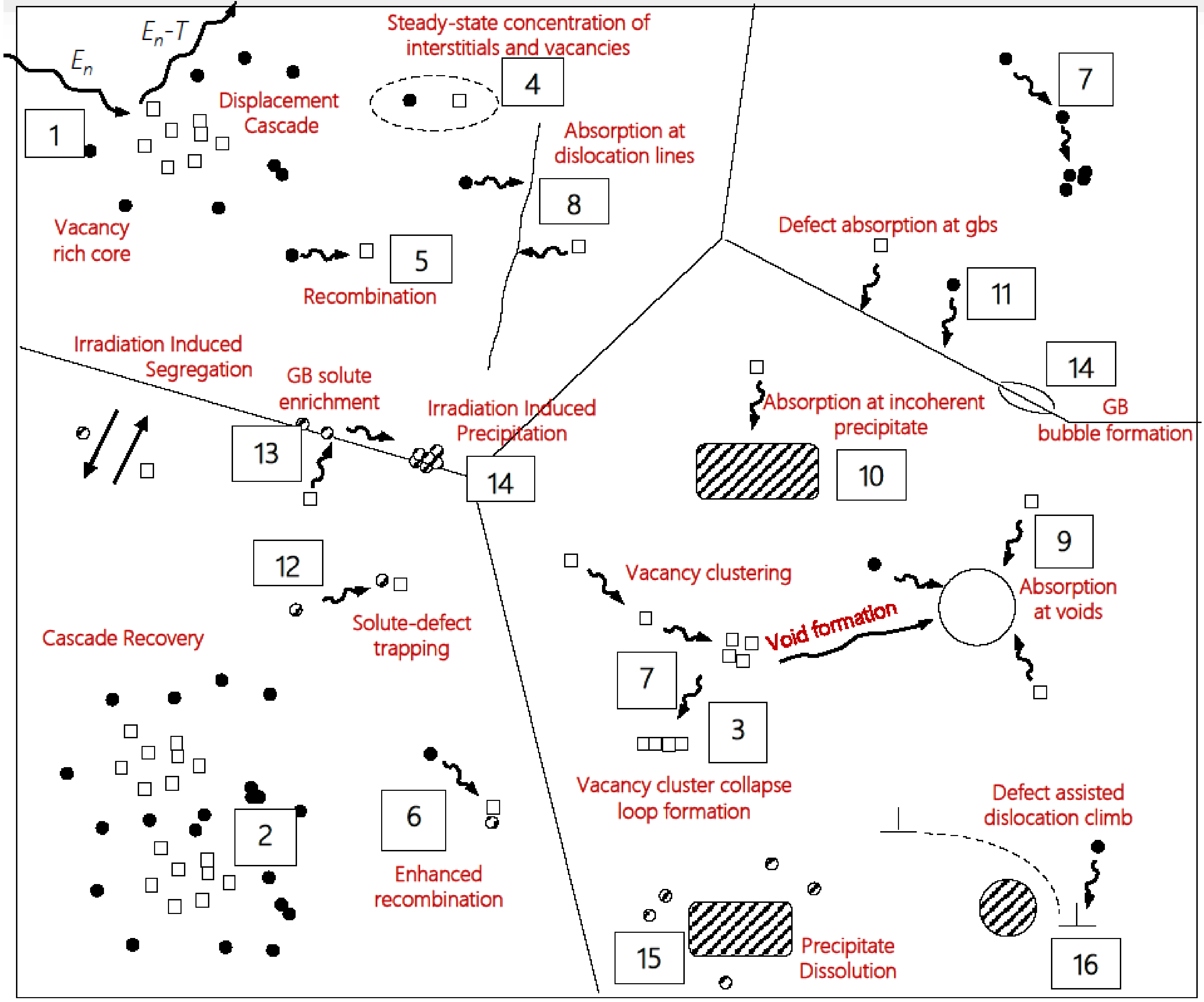
Putting it into a visual



Three options exist for designing radiation resistance materials

1. Use materials with negligible point defect mobility at desired operating temperatures
   - Slow down diffusion, but ideally want one defect type (e.g. vacancy/interstitial) mobile but the other not (to avoid amorphization/disordering)
2. Use materials with intrinsic resistance to radiation damage accumulation
   - Increased defect formation energies (e.g. stacking fault energies)
   - Examples: BCC alloys, high entropy/multicomponent alloys, nanocrystalline materials
3. Make materials with a high density of benign nanoscale recombination sites
   - Add microstructural features such as precipitates or nanolayered structures

Sinks and defect reactions

- Grain boundaries and voids classicly act as ____________?
  - Neutral sinks
  - Biased sinks
  - Variable sinks

- You are asked to derive the reaction rate for a platelet precipitate and get a prefactor of $4\boldsymbol{\pi}$ to account for the geometry. How much confidence do you have in your answer?
  - Low
  - Moderate
  - High

Sinks and defect reactions

- Which of the following defects/sinks are NOT unique to irradiated materials microstructures?
  - Line dislocations
  - Helium bubbles
  - Radiation-induced segregation
  - Dislocation loops

Radiation Induced Segregation

- If $\left(\frac{d_A^v}{d_B^v} - \frac{d_A^i}{d_B^i}\right)$ is positive, then A atoms will __________ to neutral defect sinks:
  A. Enrich
  B. Deplete
  C. Do nothing

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Radiation Induced Segregation

- Decreasing the dose rate will ___________ the peak temperature for RIS:
  A. Increase
  B. Decrease

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Radiation Induced Segregation

- Your colleague proposes to introduce a third element in small quantities to a binary alloy that would change the vacancy migration energy of one of the primary alloying elements to reduce RIS. Is this a possible mechanism to reduce RIS?
  A. Yes
  B. No
  C. Depends

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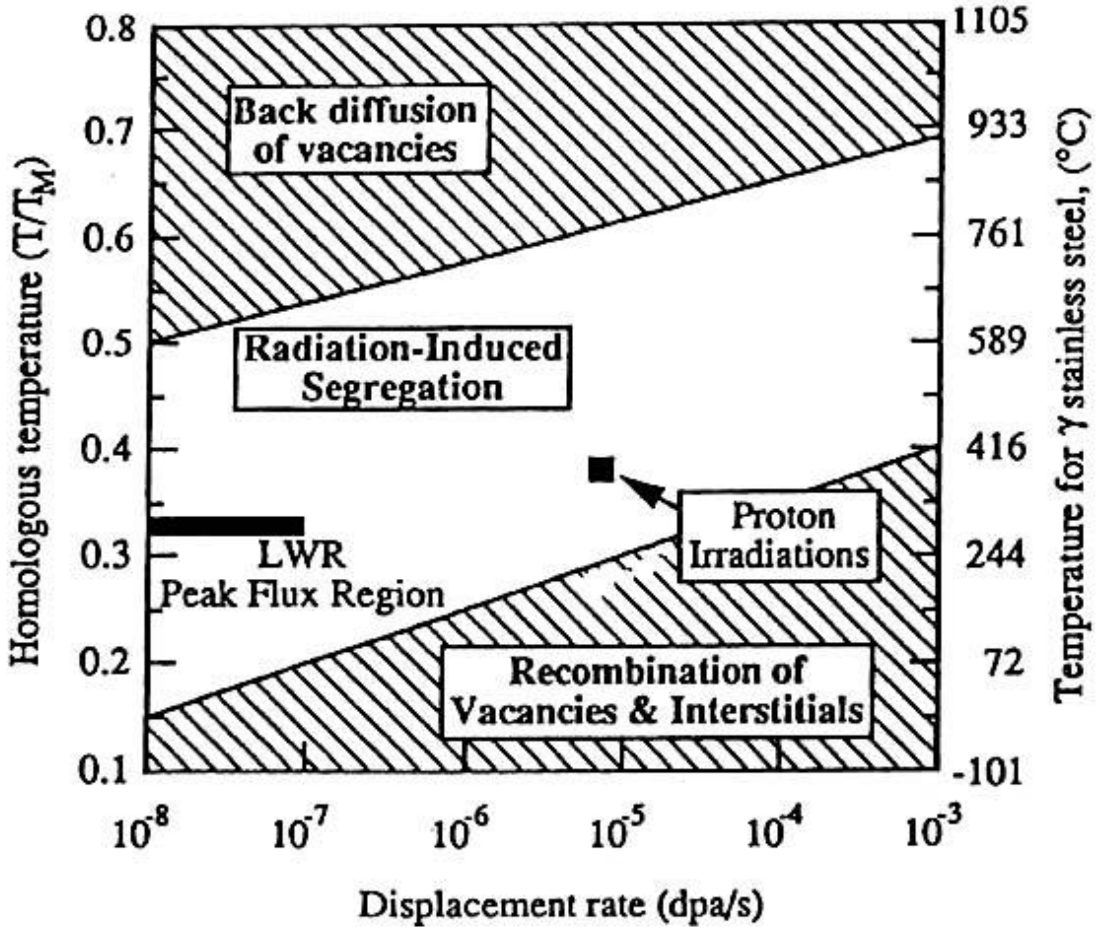
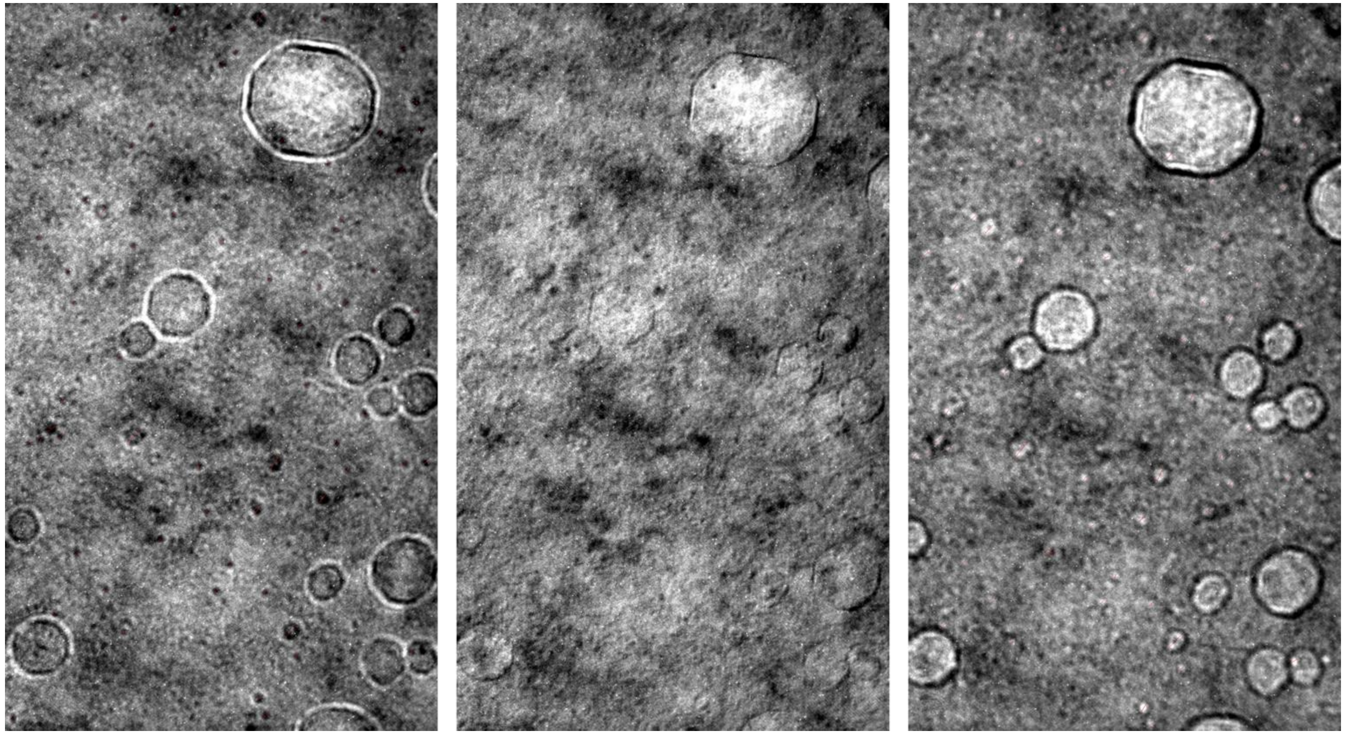
Radiation Induced Segregation



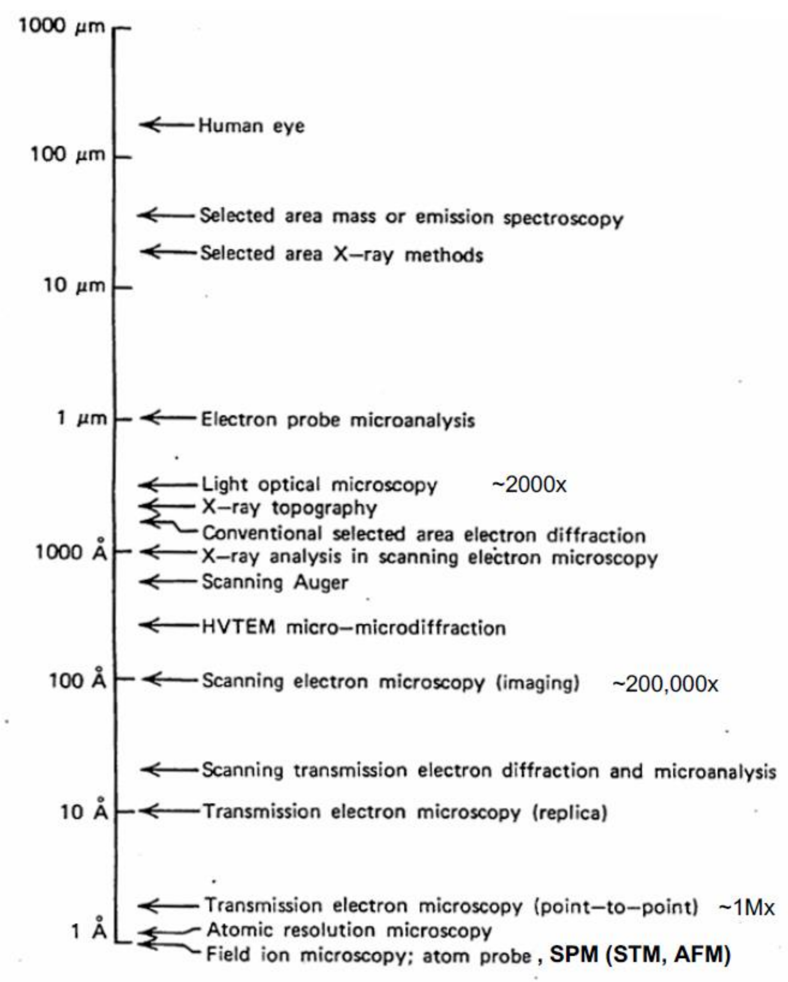
$$\nabla C_A = \frac{N_A N_B d_{Bi} d_{Ai}}{\alpha(d_{Bi} N_B D_A + d_{Ai} N_A D_B)} \times \left(\frac{d_{Av}}{d_{Bv}} - \frac{d_{Ai}}{d_{Bi}}\right) \nabla C_v$$

Characterization of Radiation Effects

- The following set of images are produced using what type of characterization technique?
    - A. TEM
    - B. SEM
    - C. XRD
    - D. APT



Characterization of Radiation Effects



- Questions are almost always:
  - What does it look like?
  - What is it made out of?
- XPS
- XRD
- SIMS
- AFM
- **TEM**
- **SEM**
- RBS
- NRA
- **APT**
- **EDS**
- **EELS**
- Many more!

On February 9, 1934, Vanderbilt, Michigan set the state's all-time coldest temperature at an incredible -51°F. Only **11 states** in the nation have ever recorded temperatures colder than that. Everyone gets one guess to get to all 11 states named. If the class gets all 11, everyone gets a bonus point.

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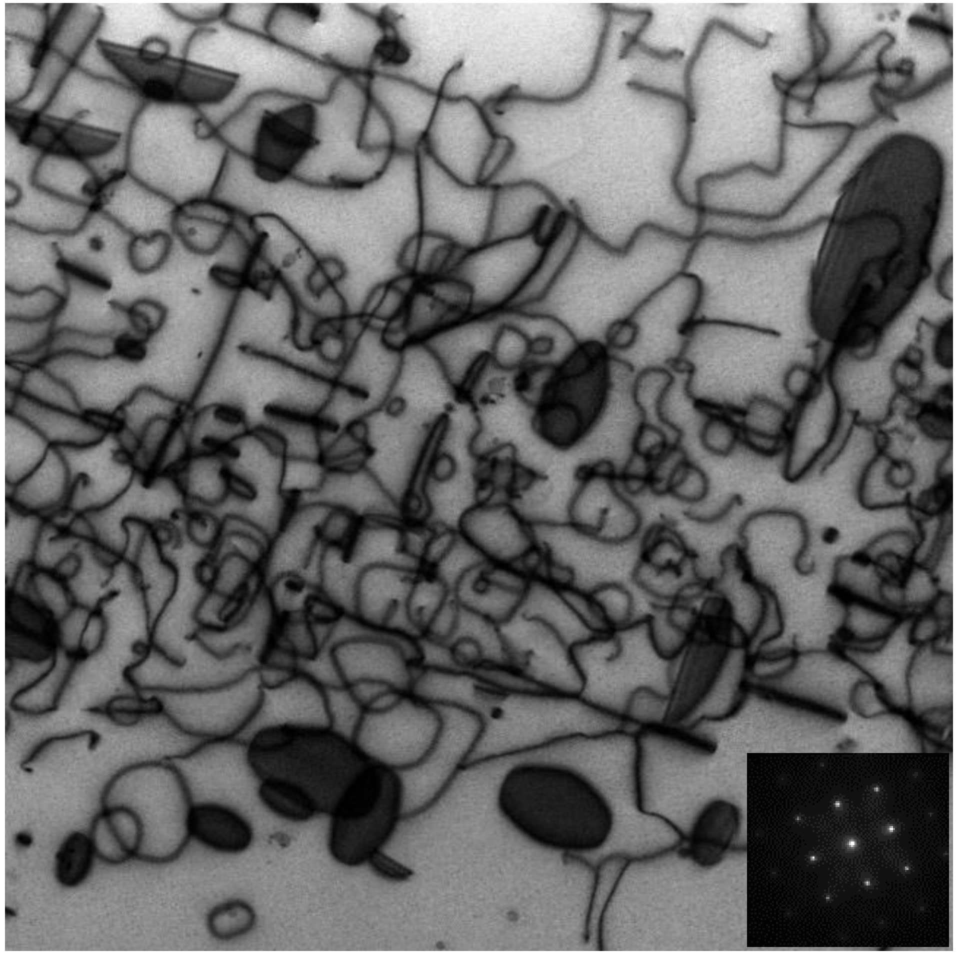
Dislocation loops

- Dislocation loops can grow by either absorption or emission of point defects under irradiation
    A. True
    B. False

Formation Energies

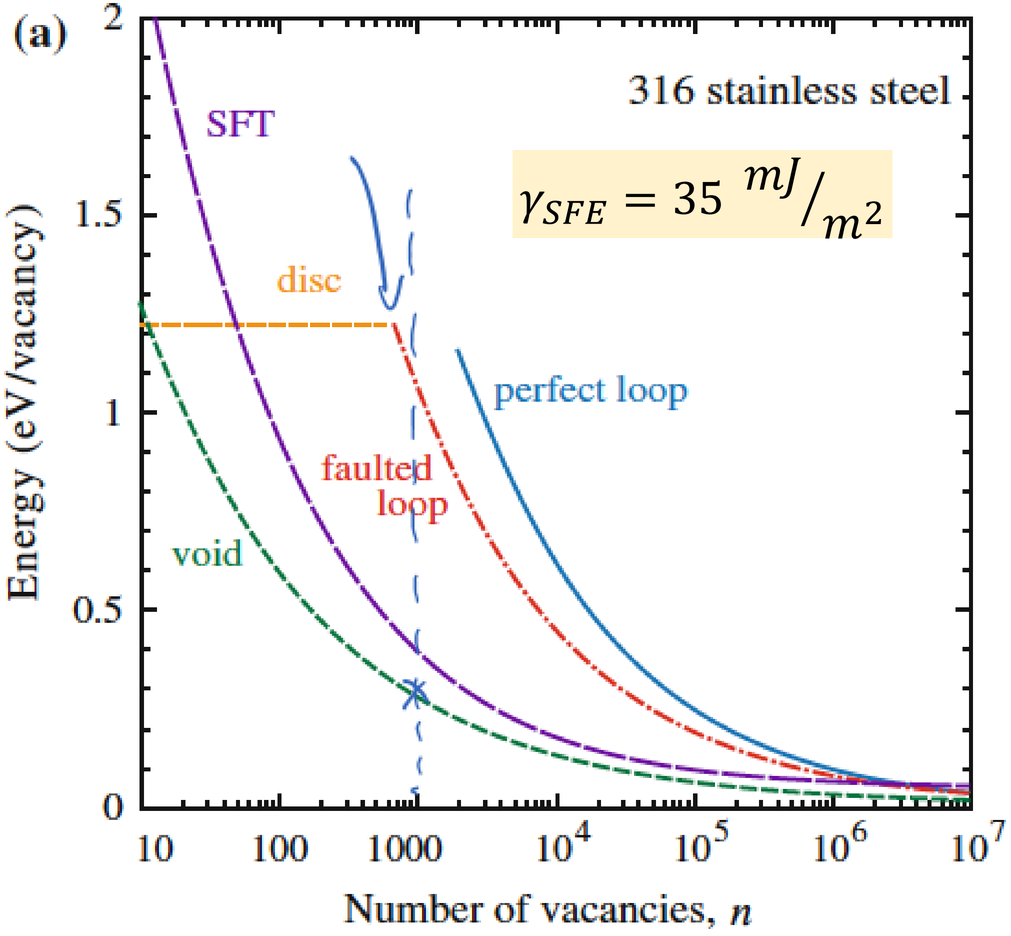
- In the micrograph for dislocation loops, the loops with “shadow” contrast are:
  A. Faulted loops
  B. Unfaulted lops

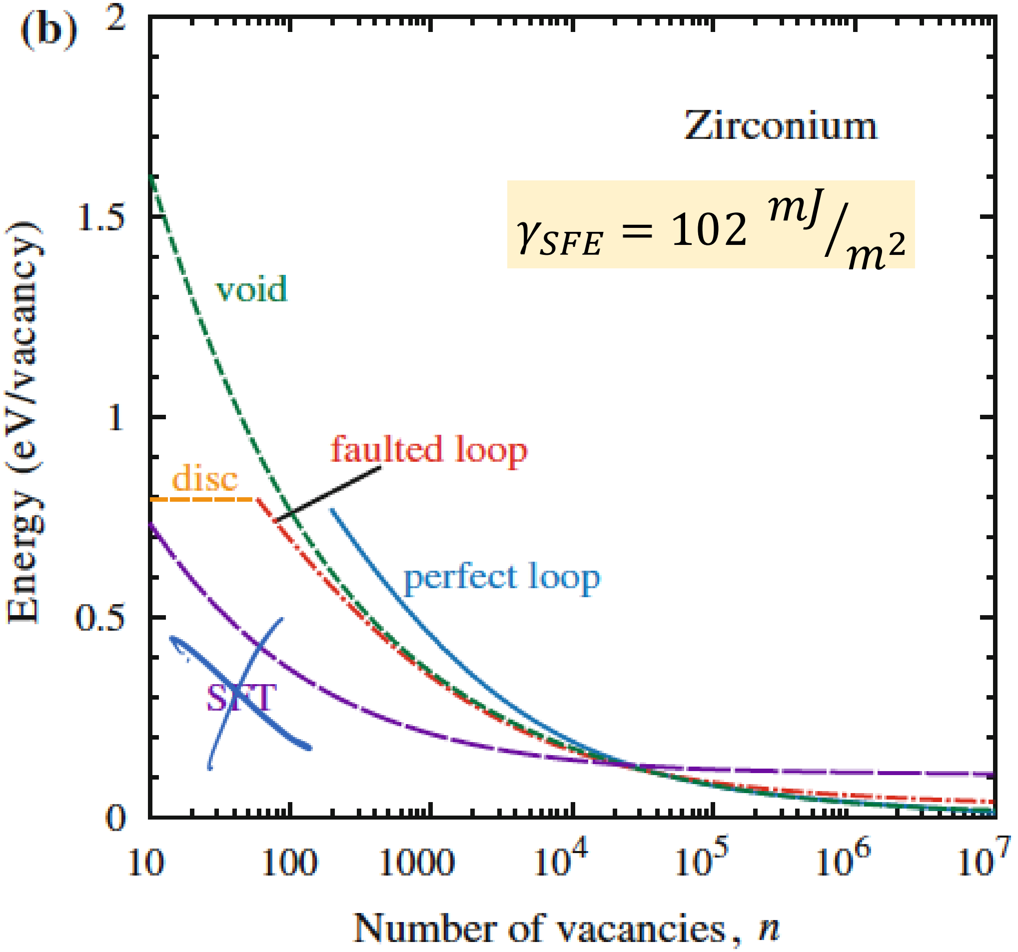


Formation Energies

- When the stacking fault energy is high, faulted dislocation loops are:
    A. Less stable
    B. More stable

Visualizing the energetics



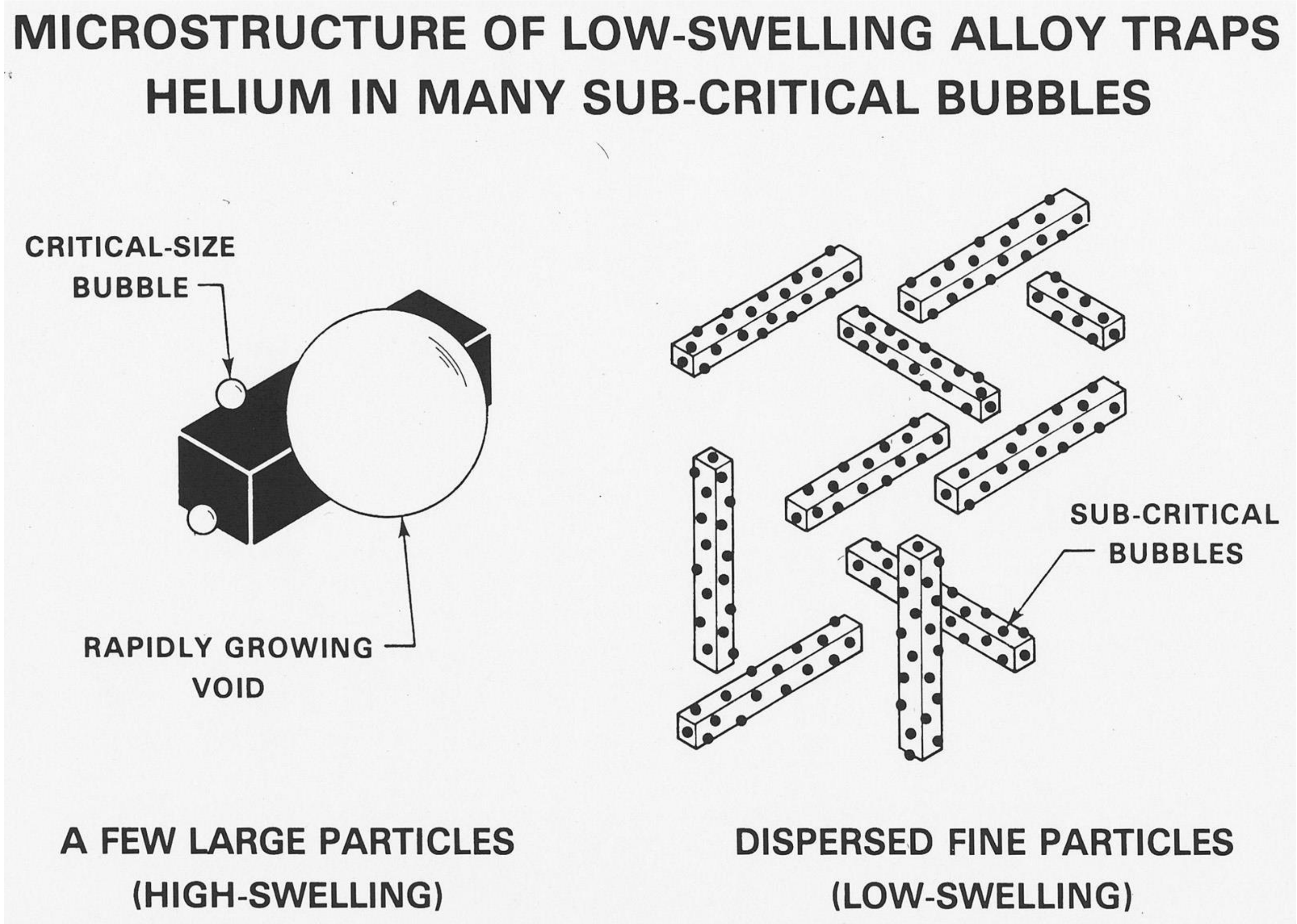


Void nucleation

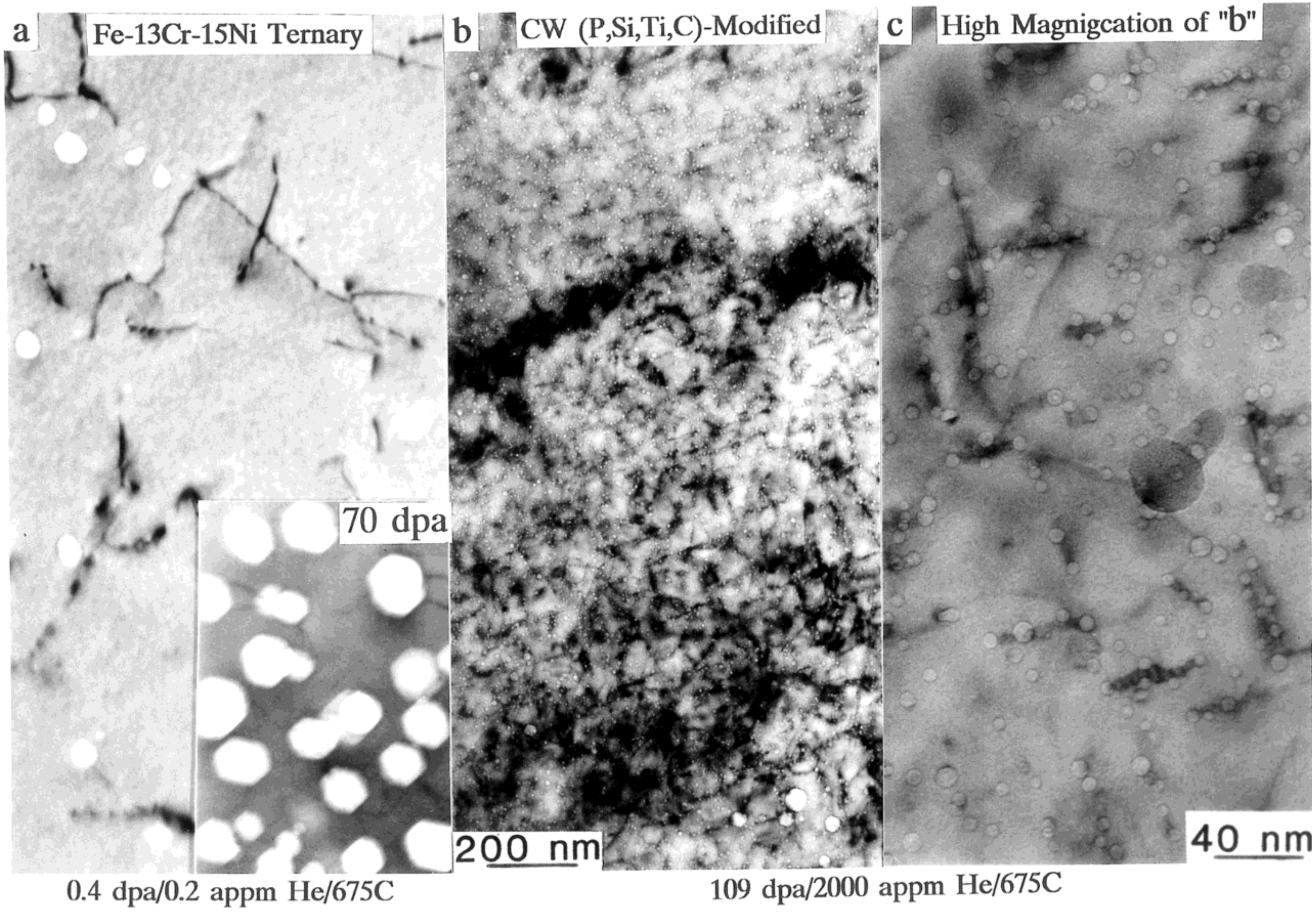
- The super saturation of vacancies, $S_v = \frac{C_v}{C_v^0}$, will:
  A. Reduce the energy barrier for nucleation of voids
  B. Increase the energy barrier for nucleation of voids
  C. Have no significant effect on nucleation of voids

- Sinks and interfaces in the material will:
  A. Reduce the energy barrier for nucleation of voids
  B. Increase the energy barrier for nucleation of voids
  C. Have no significant effect on nucleation of voids

Design for Radiation Resistance III: High Sink Strength



Design for Radiation Resistance III: High Sink Strength



L.K. Mansur & E.H. Lee, J. Nucl. Mater. 179-181(1991) 105

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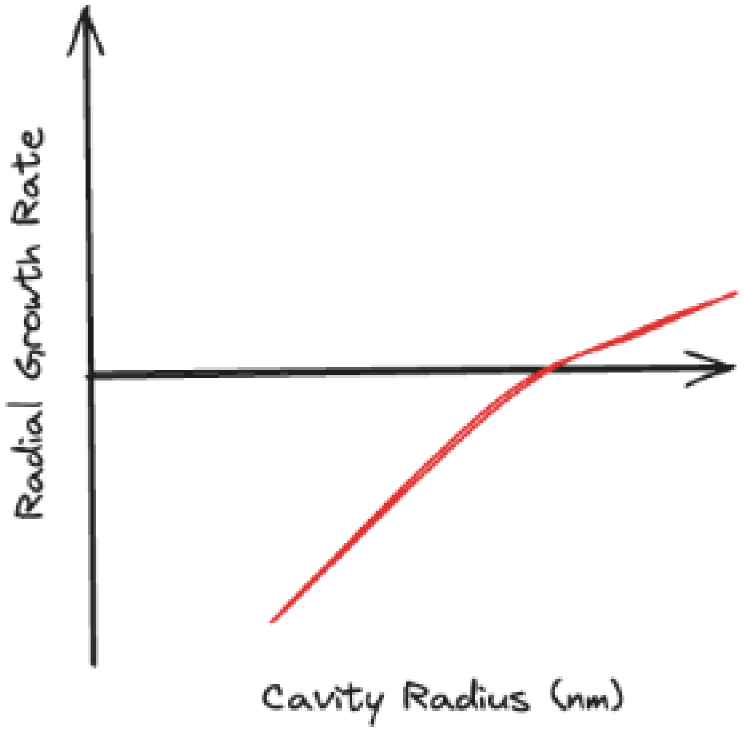
Swelling

- The bell shaped curve for swelling based on temperature is due to:
  A. Recombination dominating at low temperatures, and thermal emission dominating at high temperatures
  B. Recombination dominating at high temperatures, and thermal emission dominating at low temperatures

Void growth

- The following radial growth rate curve for a cavity is representative of?
  - A void (no gas)
  - A high gas content bubble
  - A low gas content bubble



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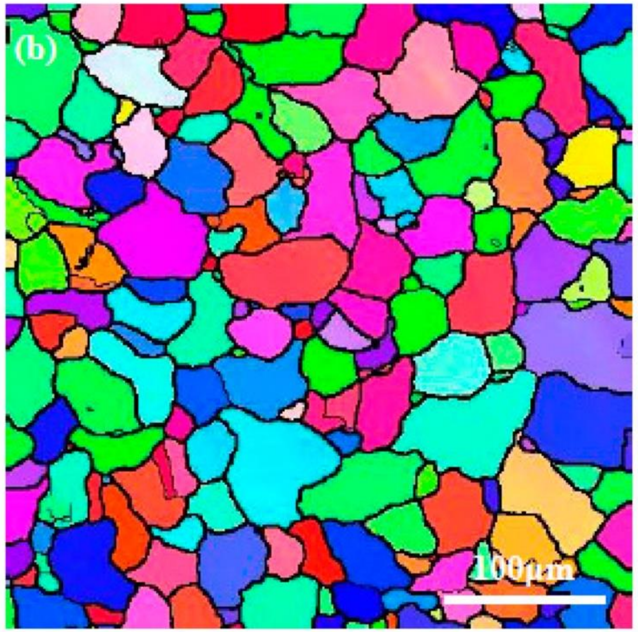
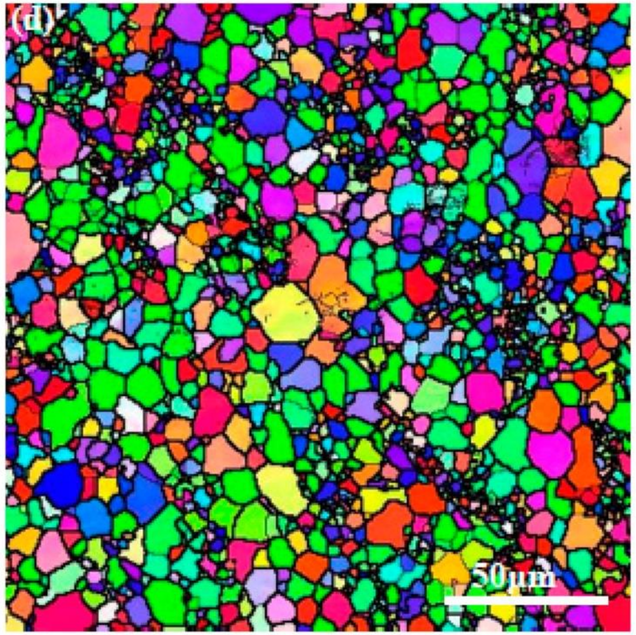
Swelling

- What material would be more resistant to swelling?



A



B

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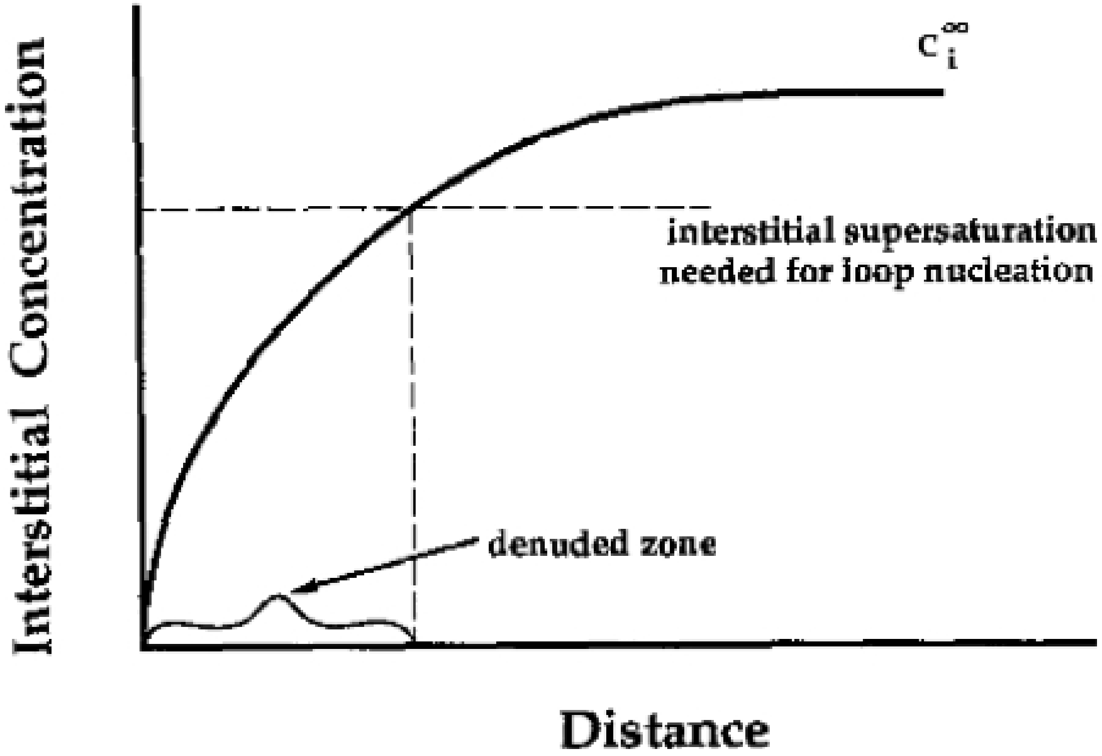
Design for Radiation Resistance III: High Sink Strength

- Early research also investigated fine grained architectures for radiation resistance, but sufficiently stable nanoscale grain boundaries were not discovered
  - Fine-grained materials are susceptible to radiation-enhanced grain growth



S.J. Zinkle, Nucl. Instr. Meth. B 91(1994)234

R. Yamada, S.J. Zinkle and G.P. Pells, J. Nucl. Mater. 209(1994) 191

L.K. Mansur & E.H. Lee, J. Nucl. Mater. 179-181(1991) 105

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Bubbles

- Gas atoms act to stabilize cavities and reduce the critical size to convert from a bubble embryo to a growing cavity.
  - True
  - False

Bubbles

- The full growth rate term can be analytically described as:

$$R\dot{R} = K_o\Omega\left(\frac{z_i - z_v}{z_v}\right)\frac{z_v\rho_d}{(4\pi R\rho_v + z_v\rho_d)^2}F(\eta) - \frac{D_v C_v^0 \Omega^2 z_v \rho_d}{kT(4\pi RN + z_v\rho_d)}\left(\frac{2\gamma}{R} - \frac{n_x kT}{{}^4/_3\,\pi R^3 - n_x B}\right)$$

The different terms in order are:

A. Dose rate response, bias response, sink balance (Q), recombination response, thermal emission, gas response

B. Bias response, dose rate response, gas response, sink balance (Q), recombination response, thermal emission,

C. Bias response, gas response, sink balance (Q), recombination response, thermal emission, dose rate response,

D. Recombination response, bias response, sink balance (Q), dose rate response, thermal emission, gas response

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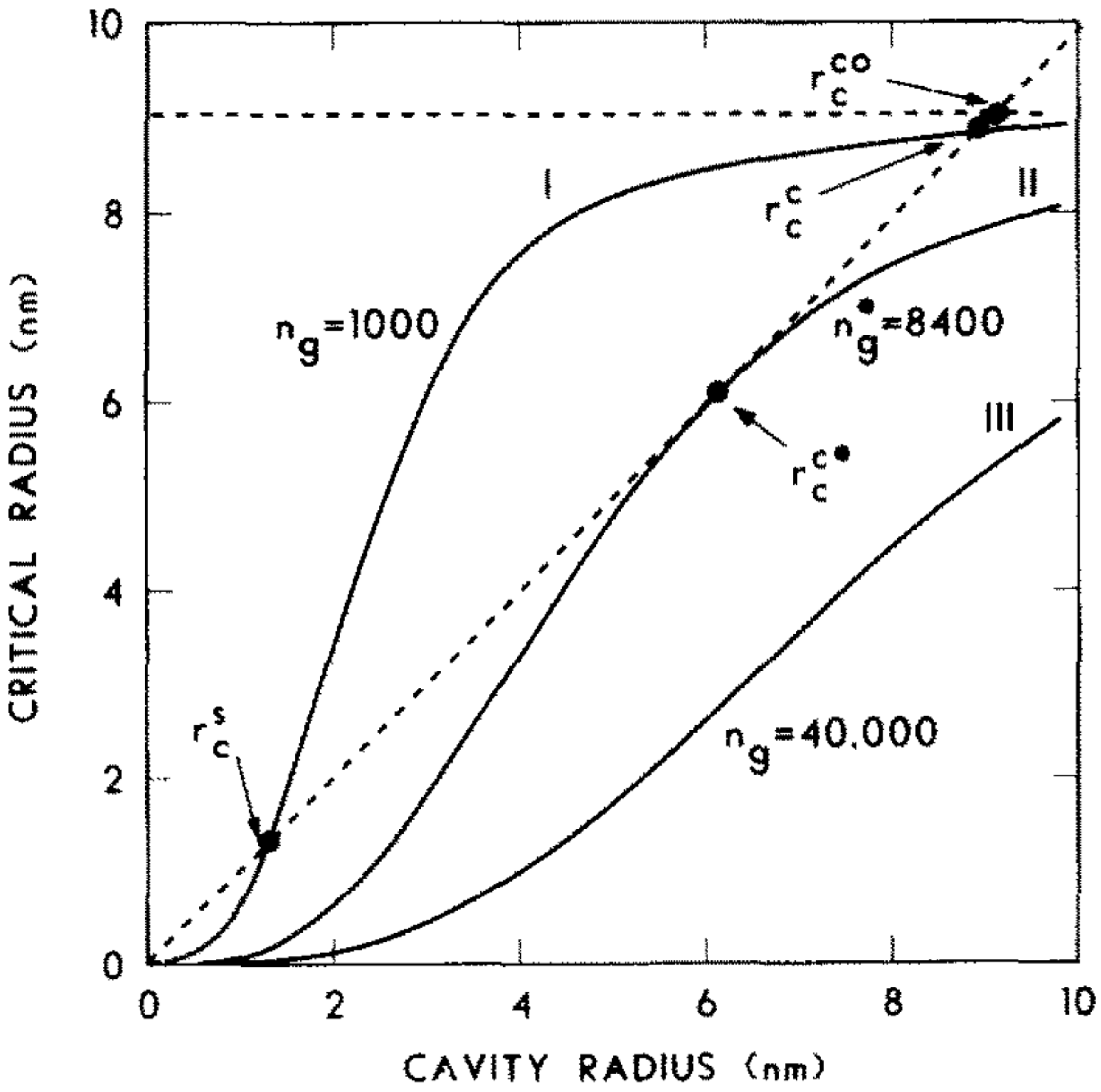
Effect of gas atoms on bubble nucleation + growth



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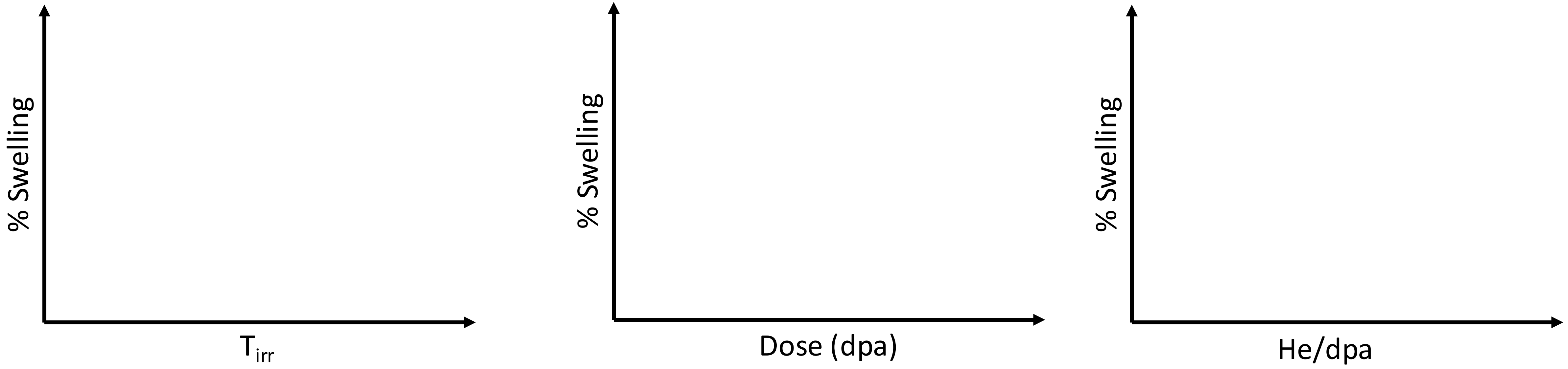
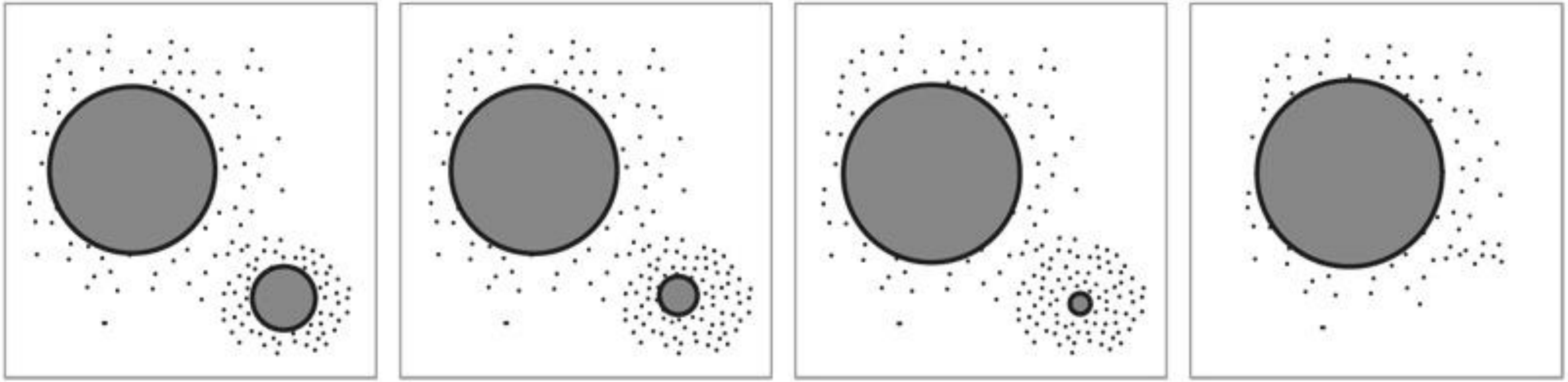
Quick review of void/bubble growth:



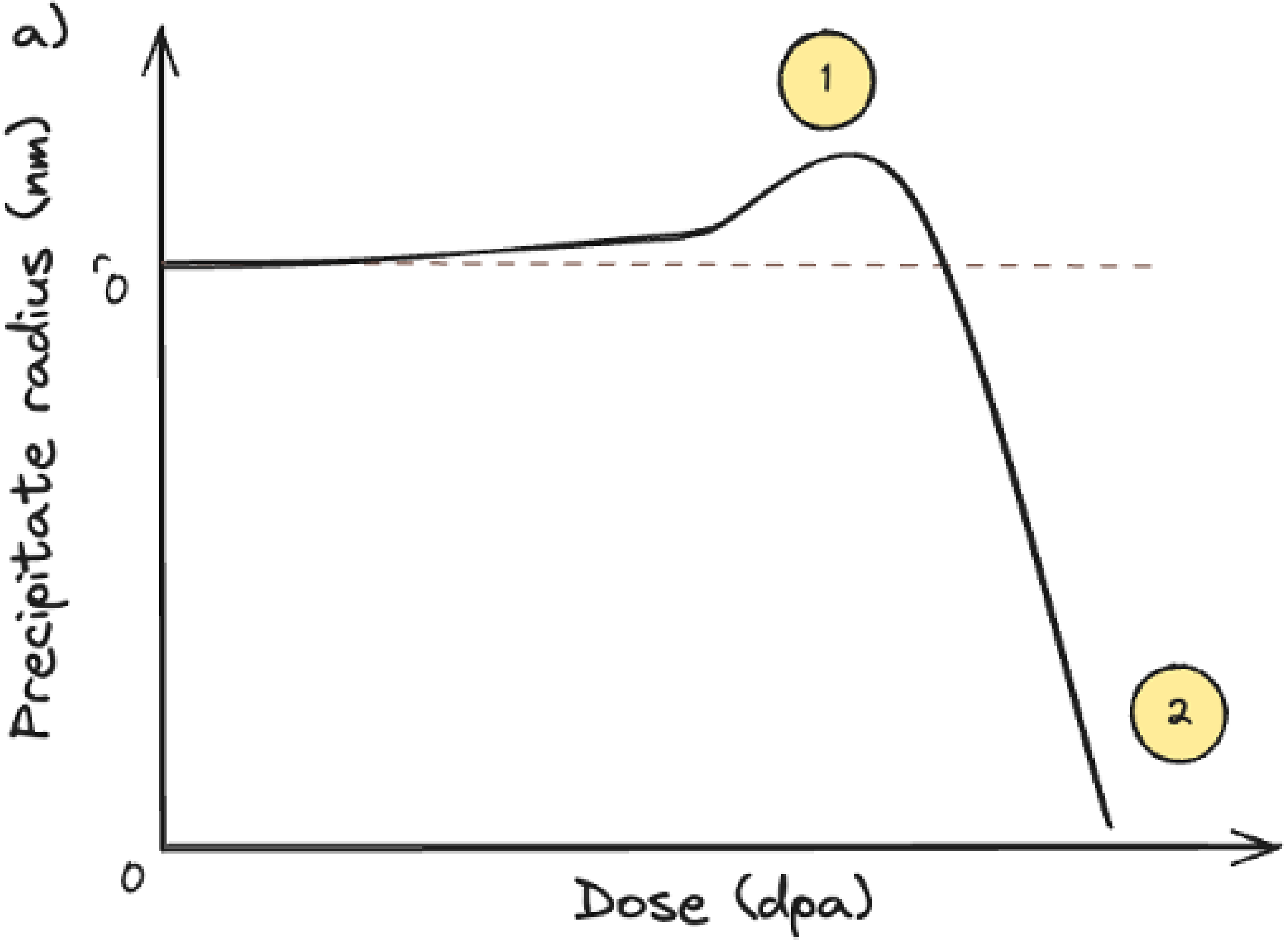
Phase stability

- Ostwald AND Inverse Ostwald ripening can be accelerated due radiation:
  A. True
  B. False



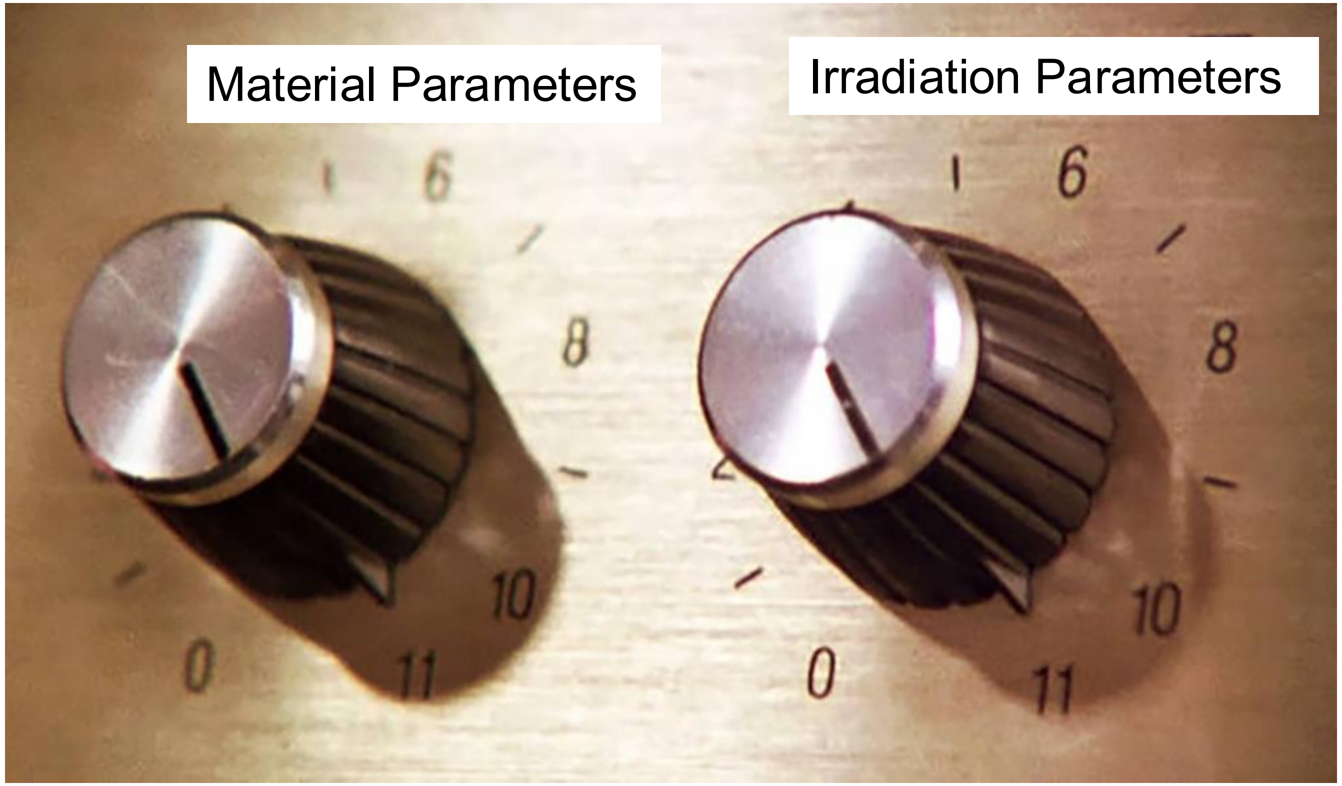
Phase Transformations

- The two primary mechanisms for precipitate stability under irradiation are:
  A. Supersaturation and dislocation density
  B. Recombination and diffusion
  C. Diffusion and ballistic effects
  D. Migration and formation energies



a)
Precipitate radius (nm)
r_0
1
2
0
Dose (dpa)

Take home message



https://www.youtube.com/watch?v=F7IZZXQ89Oc

Take home message

https://www.youtube.com/watch?v=F7IZZXQ89Oc

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Thank you!

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Questions?