Final Class Review

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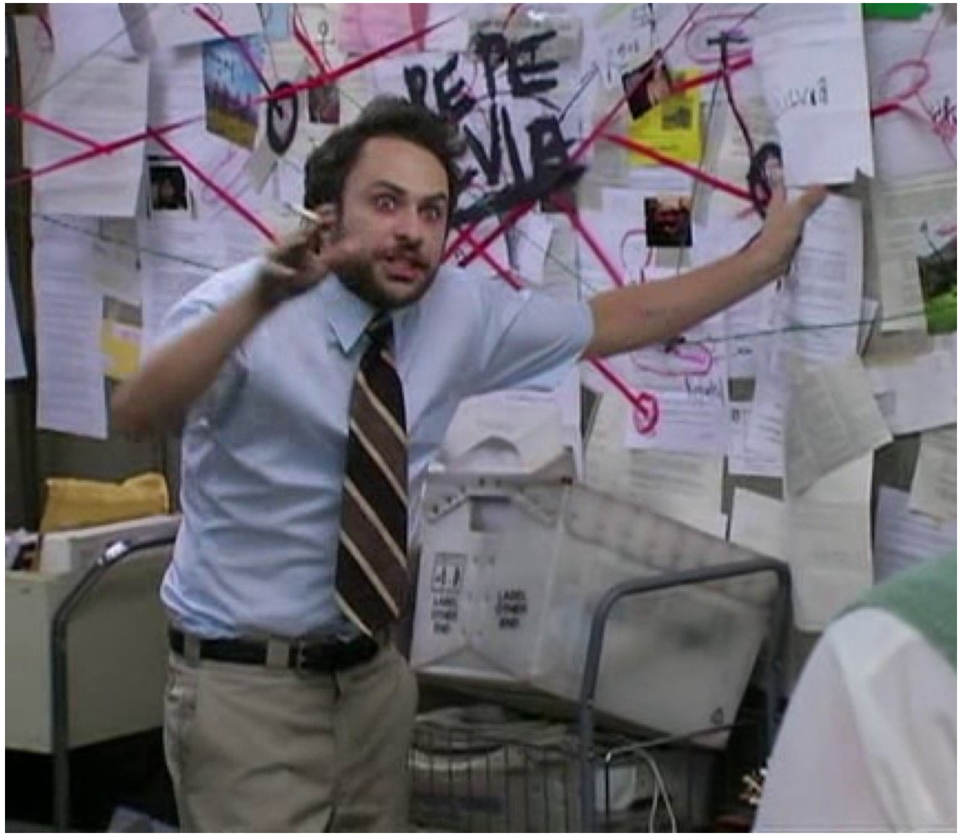
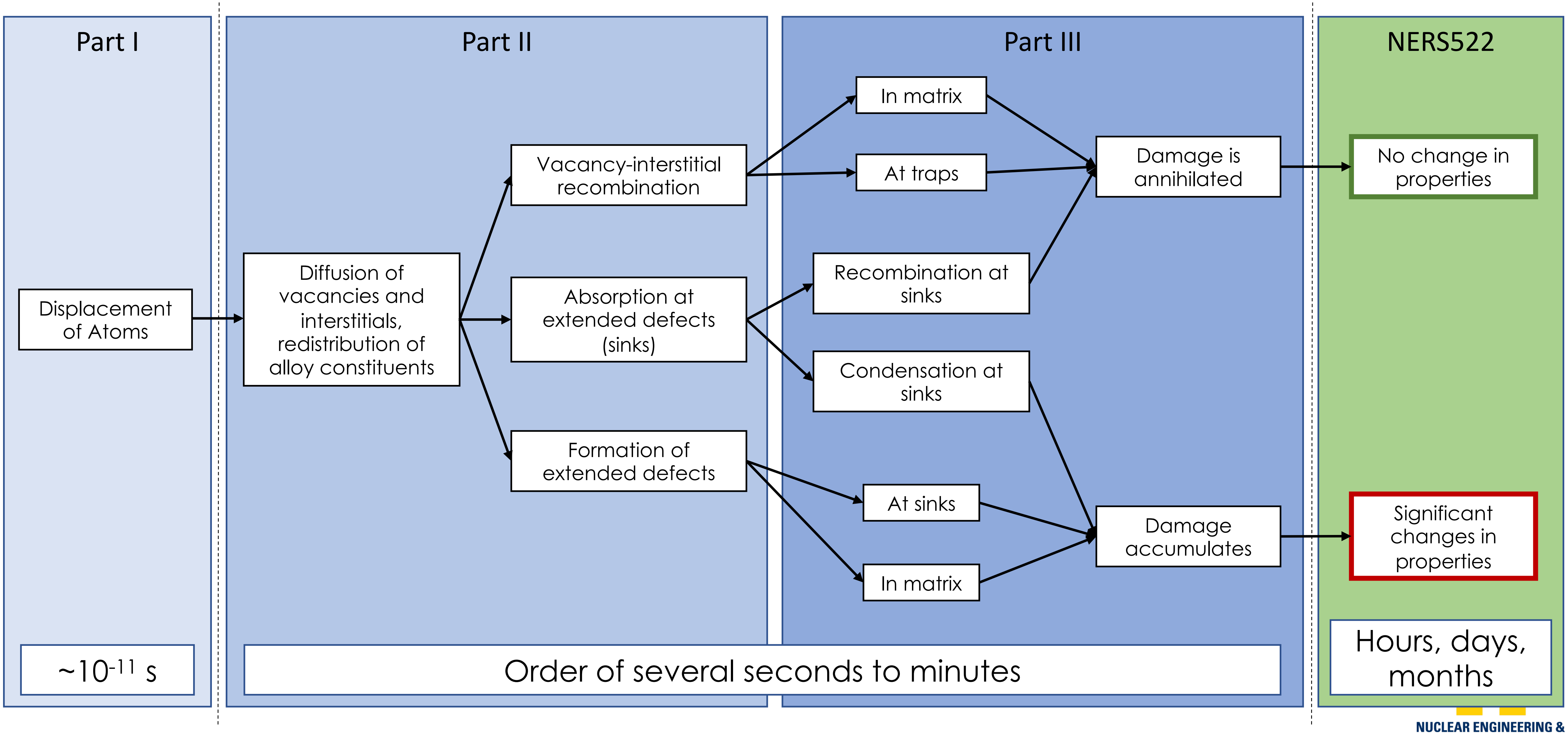
Final Exam Structure

- Dec. 14th @ 10:30 am – 12:00 pm
- Cooley 2918
- 5-6 questions, if calculations are "needed" it will be more regarding set-up of a problem or explanation of an equation or system of equations
- Same format as mid-term
- Non-cumulative, use slides as guide for topics to be covered



Flow chart for radiation damage



Louis Mansur, "Mechanisms & Kinetics of Radiation Effects in Metals and Alloys", in: Kinetics of Nonhomogeneous Processes, 1987

Displacement of Atoms in Detail

Part I

Displacement of Atoms

(Radiation Damage Event)

~10^{-11} s

Displacement of atoms is primarily evaluated as the **radiation damage event** which is composed of the following sequence of events:

1. The *interaction* of an energetic particle with a lattice atom
2. The *transfer of kinetic energy* to the lattice atom resulting in the primary knock-on atom (PKA)
3. The *displacement* of the lattice atom from it's lattice site
4. The *passage* of the displaced atom through the structure and the potential accompanying creation of additional knock-on atoms
5. The *production of a displacement cascade*
6. The *termination of the PKA* as an interstitial in the structure

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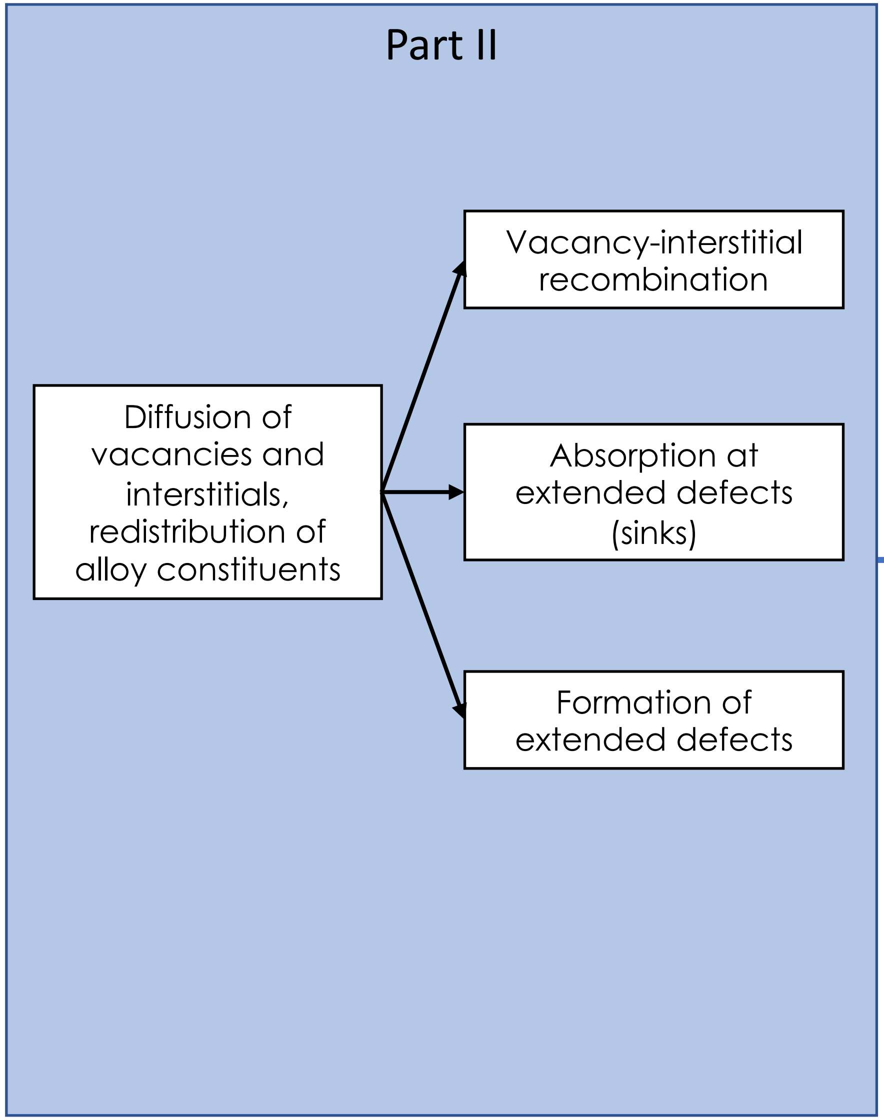
Concentration of Point Defects in Detail



Build up of point defects is typically evaluated based on **rate of events at and to defect sinks** (e.g. rate theory), where:

1. Point defects of opposite sign can recombine
2. Point defects of the same sign can agglomerate
3. Or, defects can be trapped/annihilated at defect sinks

The rates of these events are dependent on:
1. Diffusion (e.g. defect hopping)
2. Sink density
3. Sink morphology/characteristics
4. Displacement rate (e.g. defect production rate)

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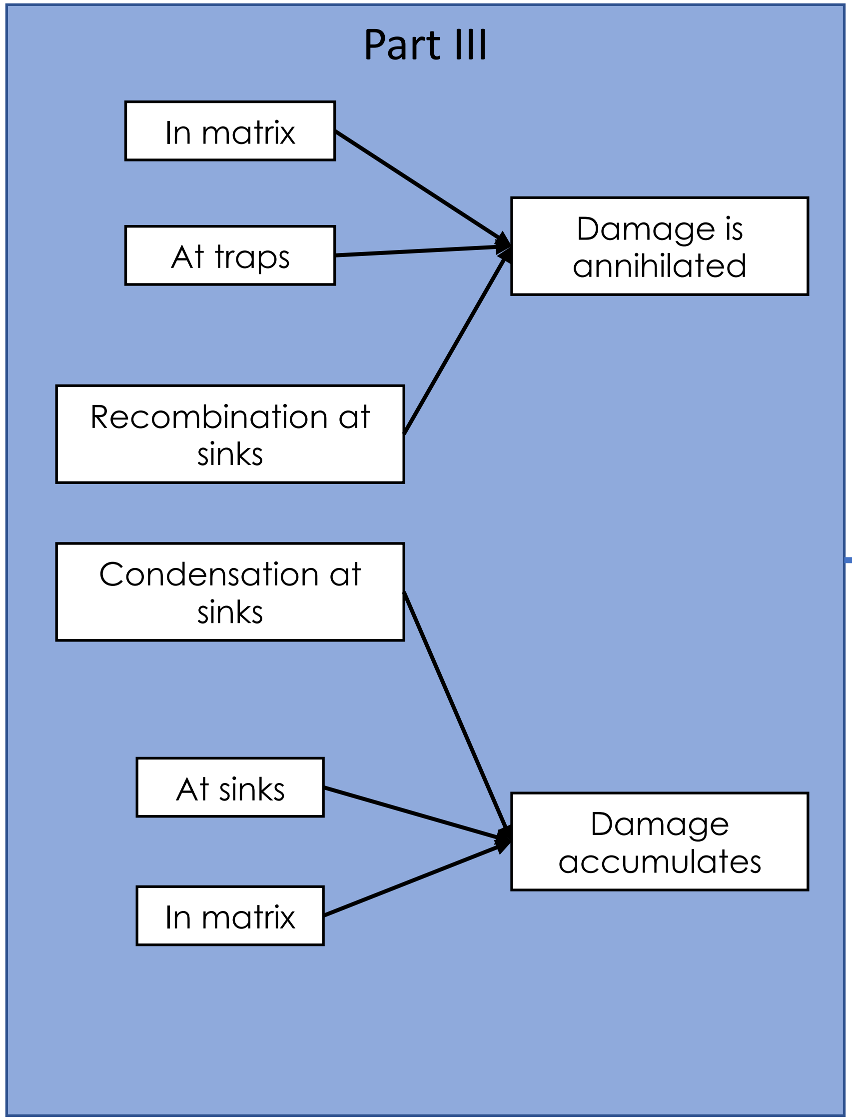
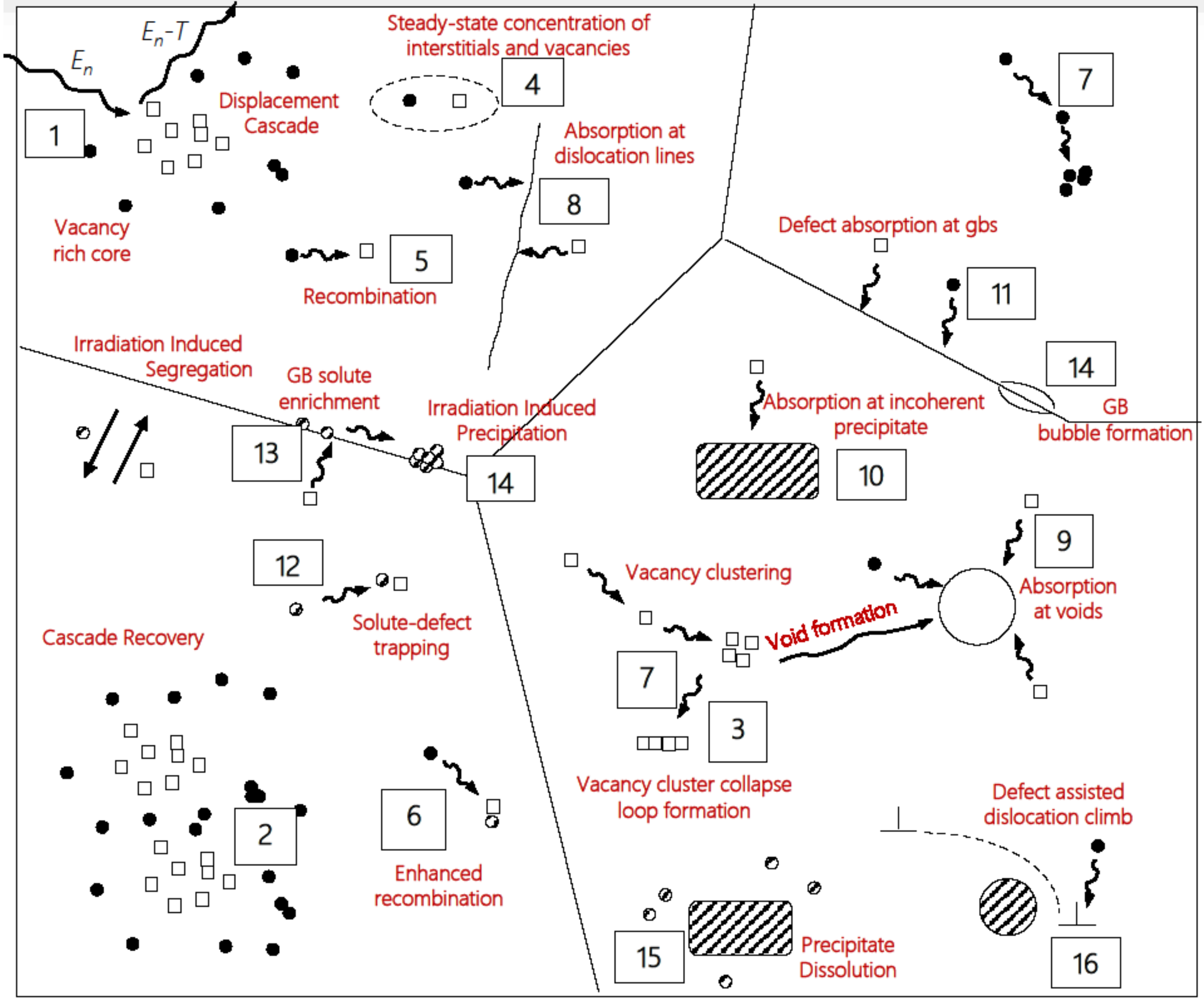
Production of Extended Defects in Detail



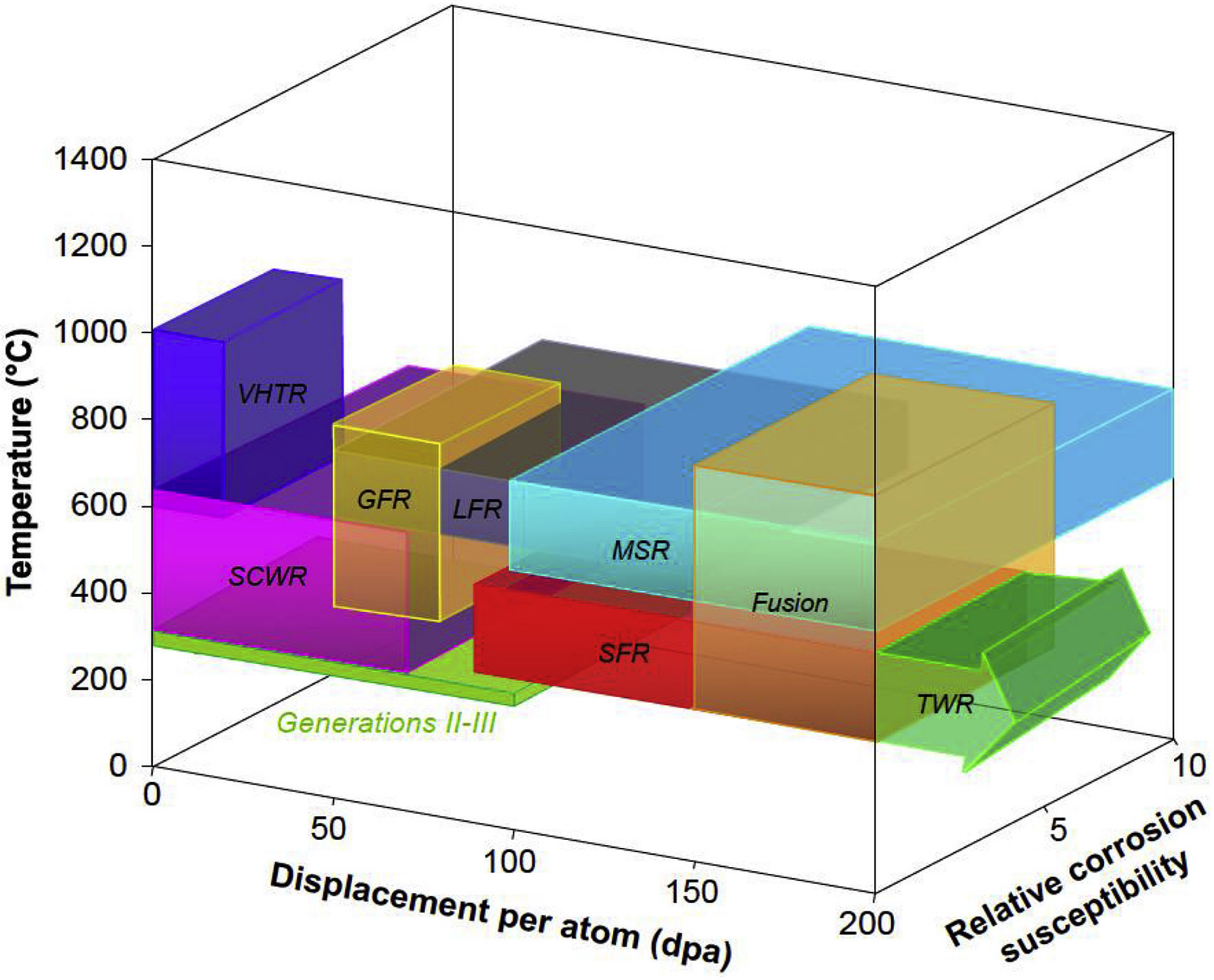
Production of extended defects is dependent on irradiation conditions where **<u>thermally activated processes (e.g. diffusion) and atomic displacements compete</u>** leading to peak radiation effects at ~0.3-0.5 T_m for most alloys. Formation of a given type of defect requires favorable energetics and point defect mobility.

<u>Material parameters</u> such as sink density and composition can be **<u>altered to reduce the response</u>**.

Putting it into a visual



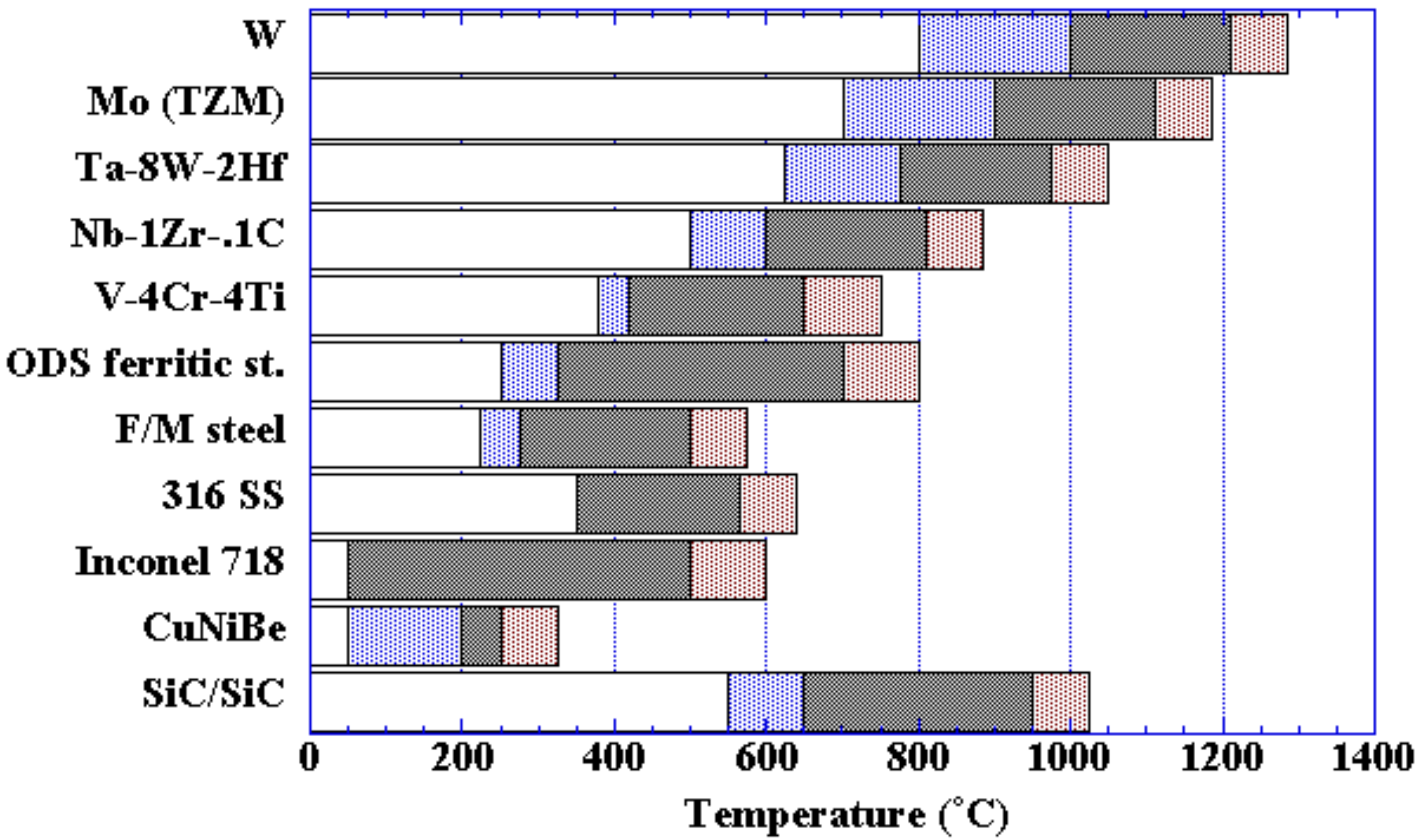
Materials "stressors" on a per reactor basis



Reactor Type	Inlet Temp (° C)	Outlet Temp (° C)	Maximum Dose (dpa)	Pressure (Mpa)	Coolant
PWR	290	320	100	16	Water
SCWR	290	500	15-67	25	Water
VHTR/FHR	600	1000	1-10	7	Helium, Salt
SFR*	370	550	200	0.1	Sodium
LFR*	600	800	200	0.1	Lead
GFR*	450	850	80	7	Helium/ SC CO_2
MSR	700	1000	200?	0.1	Molten Salt

https://doi.org/10.1016/j.jnucmat.2019.151837

Bringing it together: Radiation Materials Design



Zinkle and Ghoniem, Fusion Engr. Des. 49-50(2000) 709; S.J. Zinkle & J.T. Busby, Mater. Today 12(2009) 12

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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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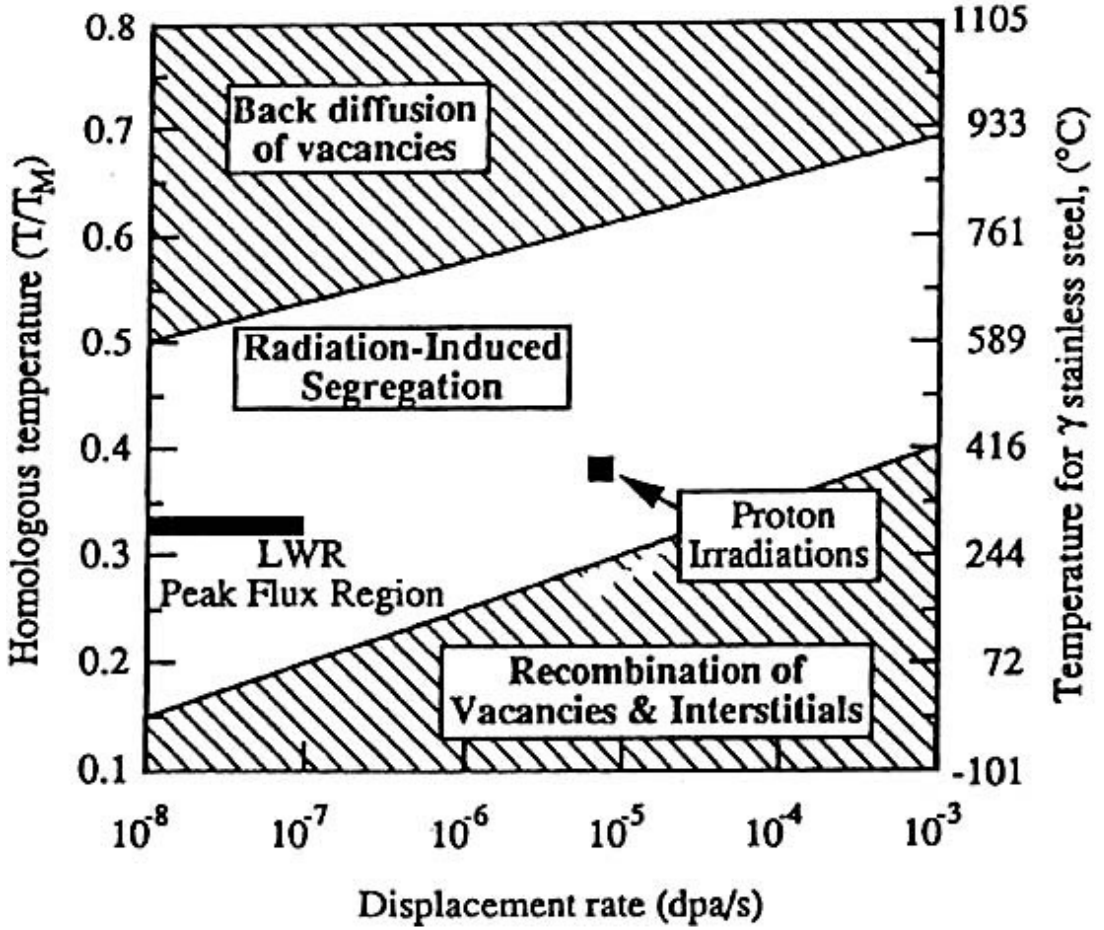
Radiation Induced Segregation

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

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

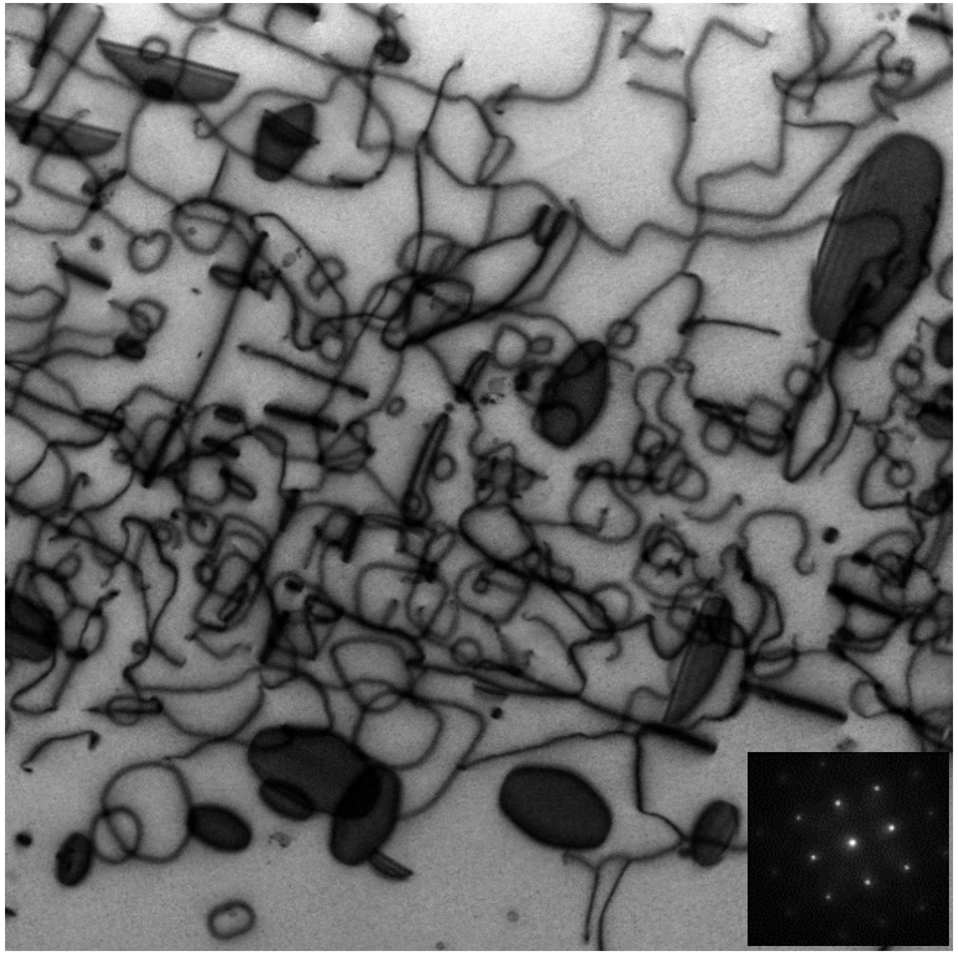
Radiation Induced Segregation



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

Formation Energies

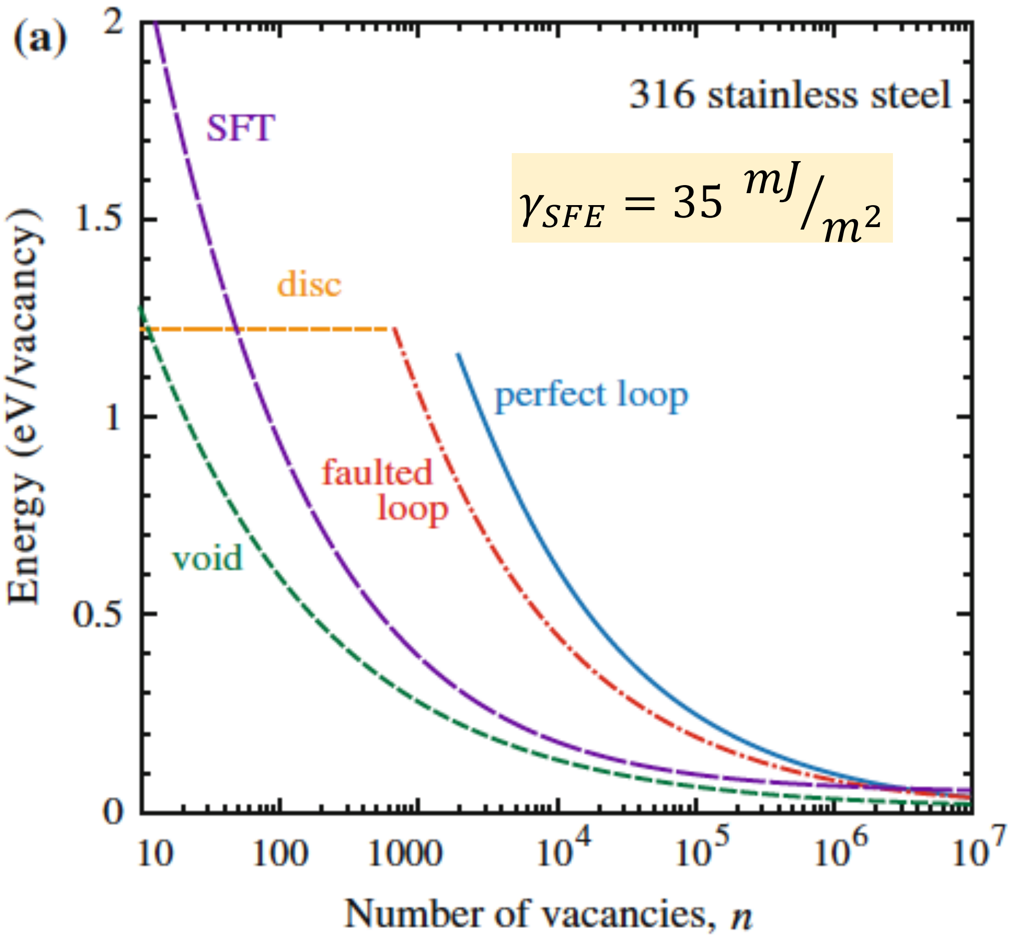
- In the micrograph for dislocation loops, the loops with “shadow” contrast are:
  A. Faulted loops
  B. Unfaulted lops

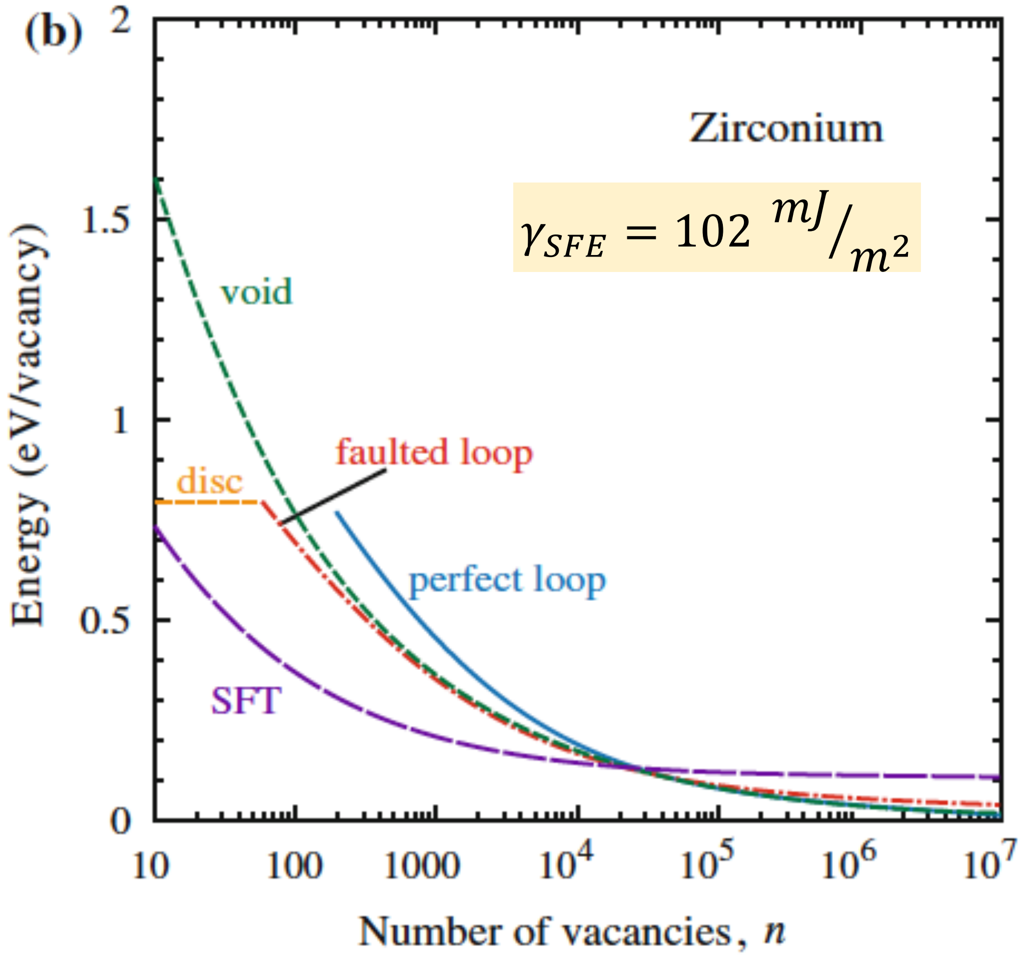


Formation Energies

- 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

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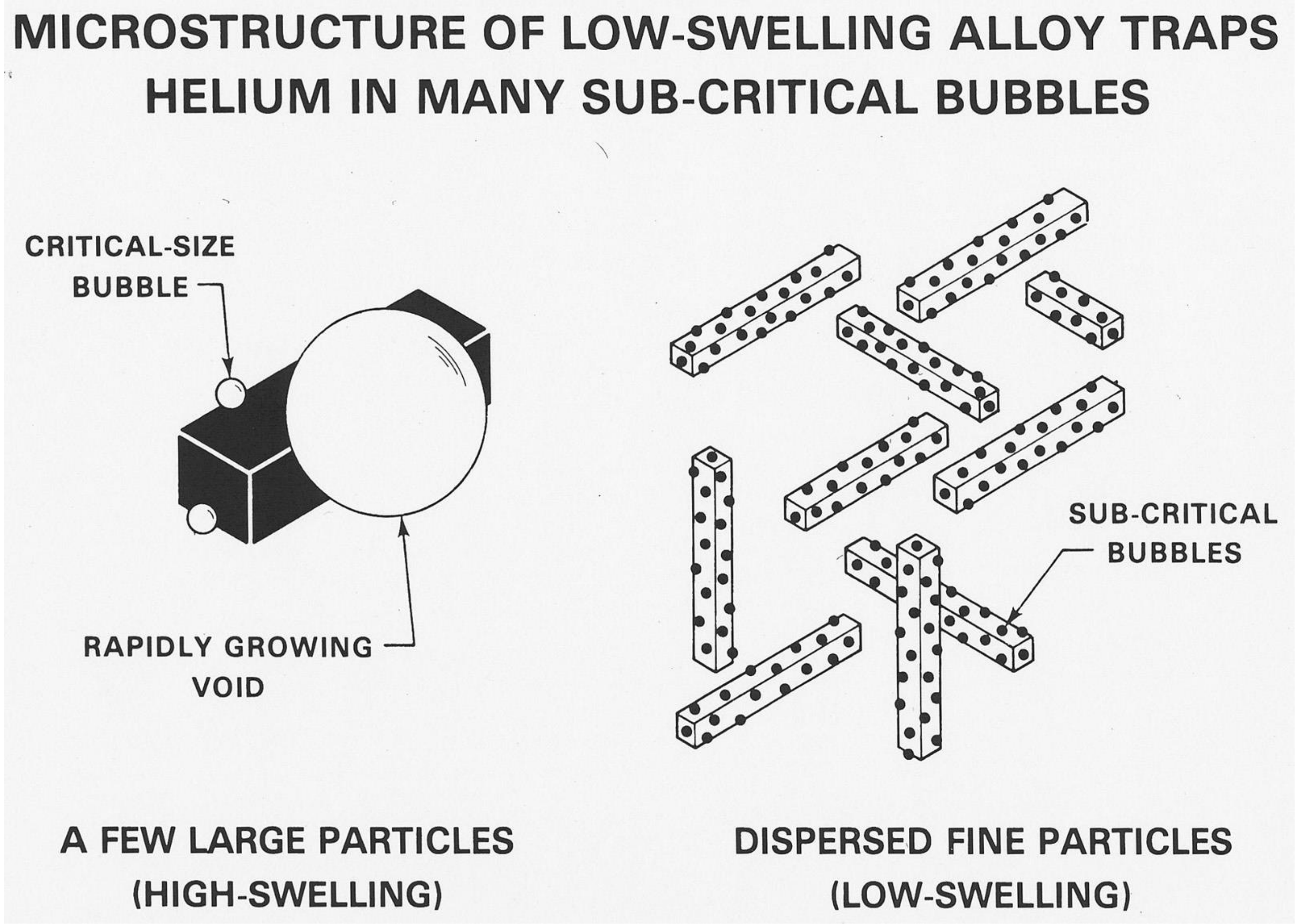
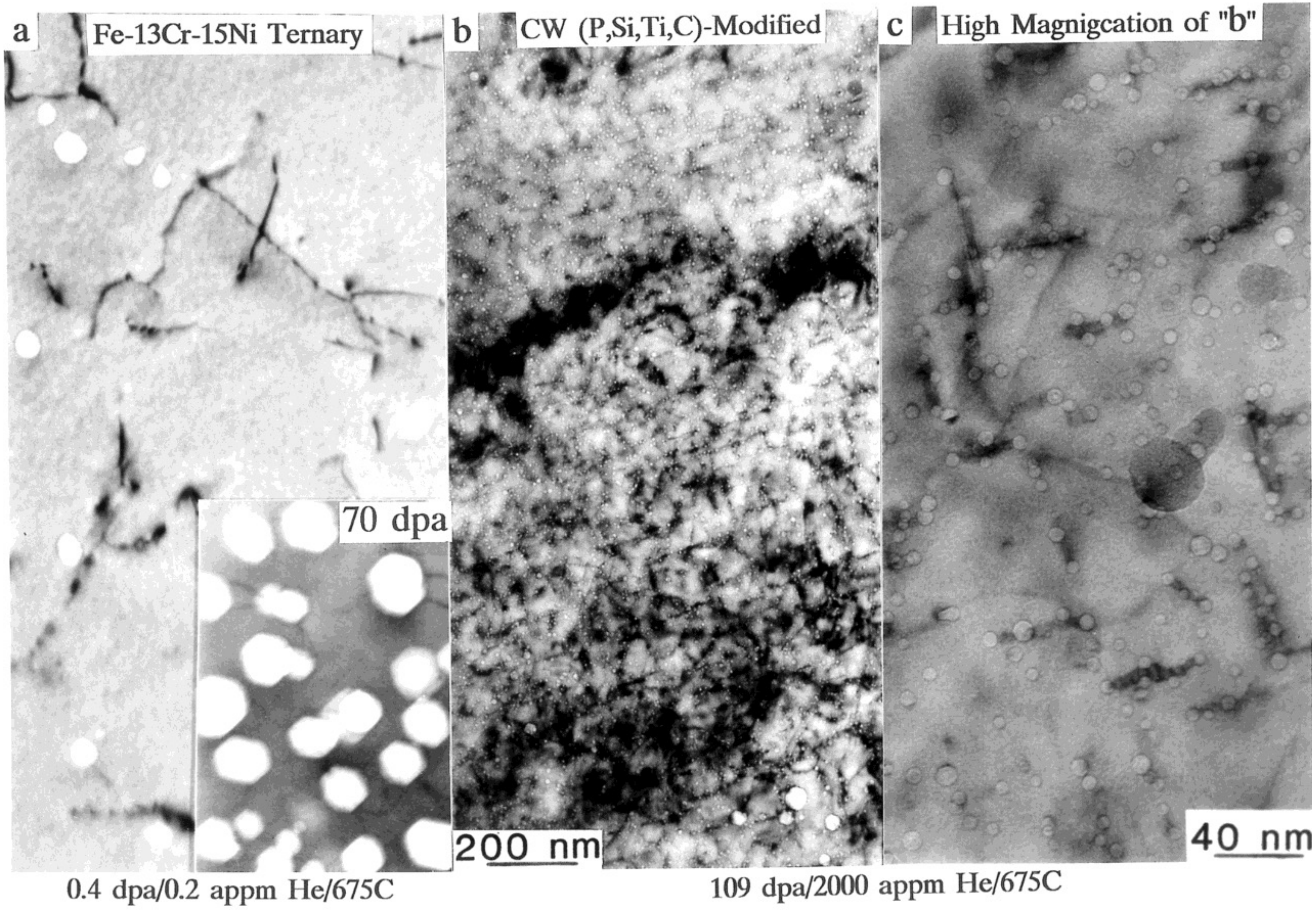
Design for Radiation Resistance III: High Sink Strength



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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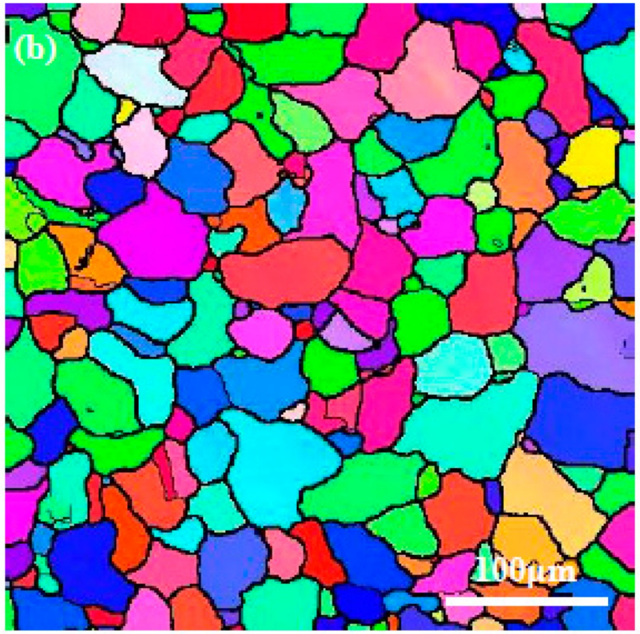
Swelling

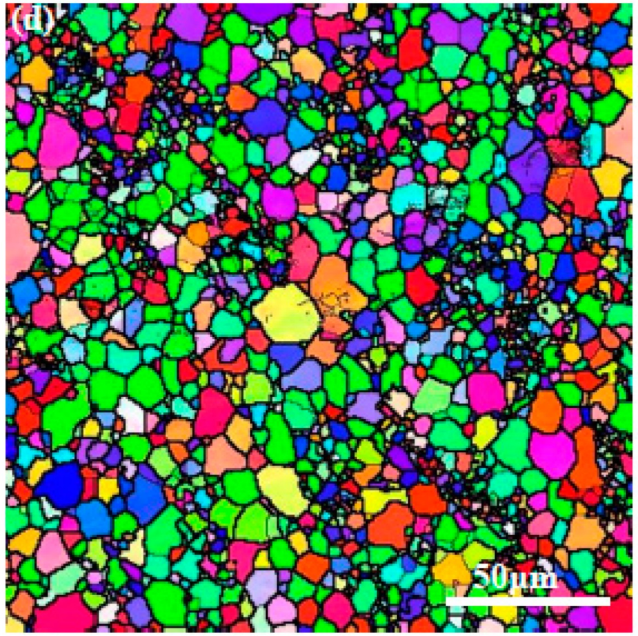
- The bell shaped curve for swelling based on temperature is due to:
  A. Recombination dominating at low temperatures, and thermal emission dominating at high temperatures
  B. Recombination dominating at high temperatures, and thermal emission dominating at low temperatures

Swelling

- What material would be more resistant to swelling?



A



B

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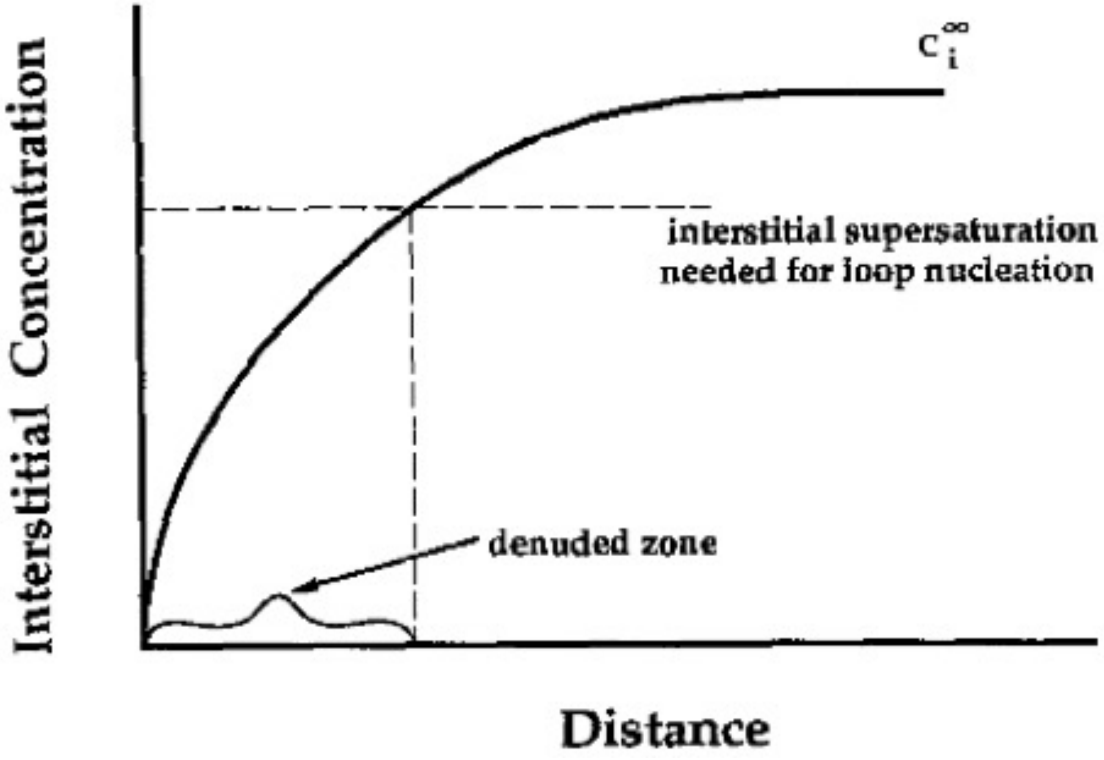
Design for Radiation Resistance III: High Sink Strength

- 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

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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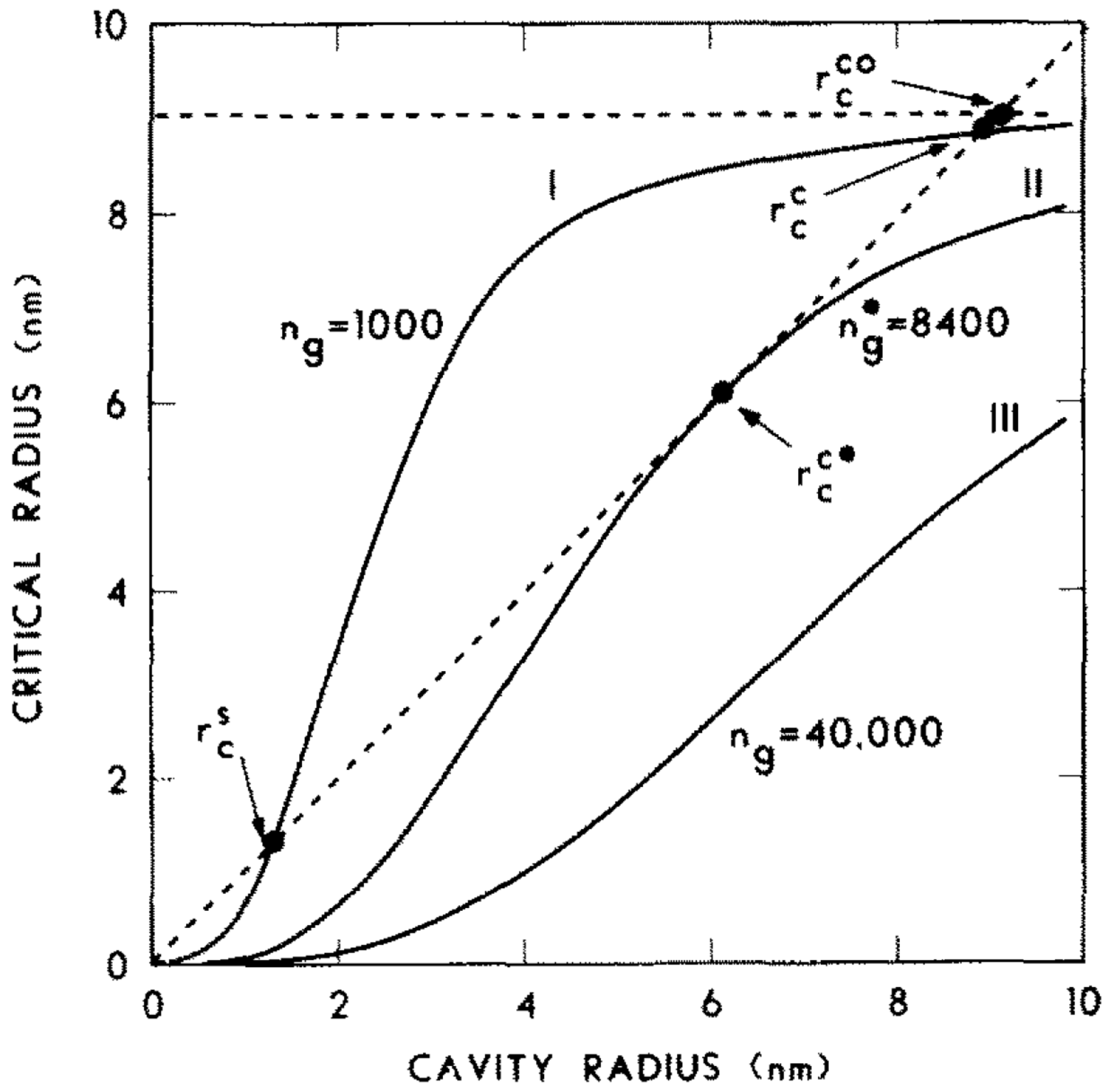
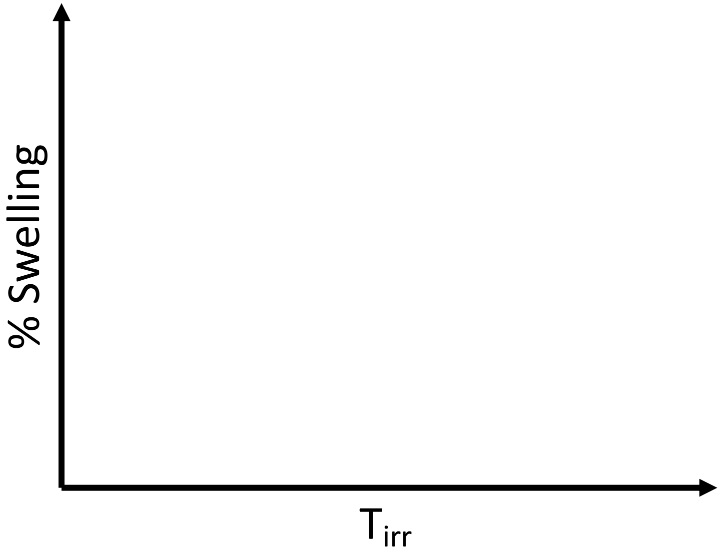
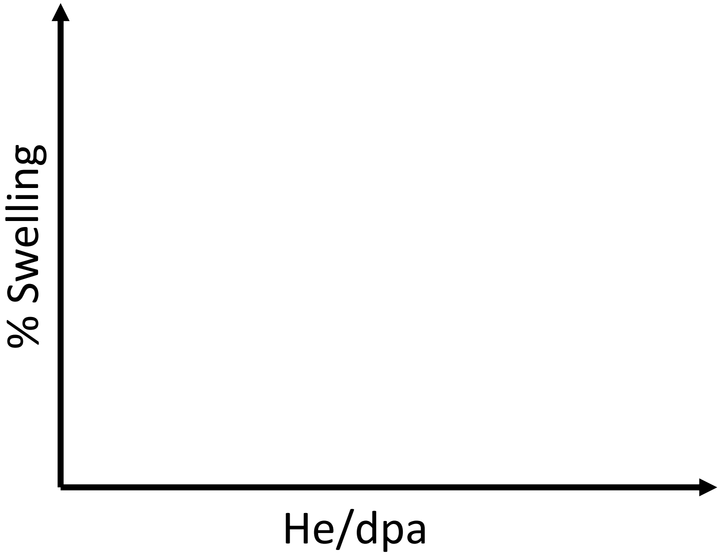
Effect of gas atoms on bubble nucleation + growth



Quick review of void/bubble growth:





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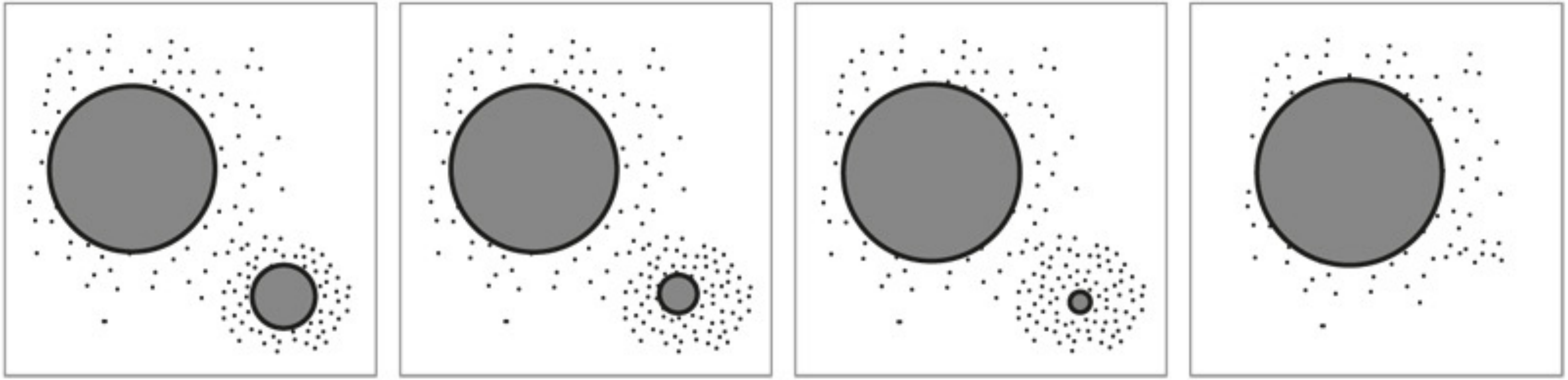
Phase stability

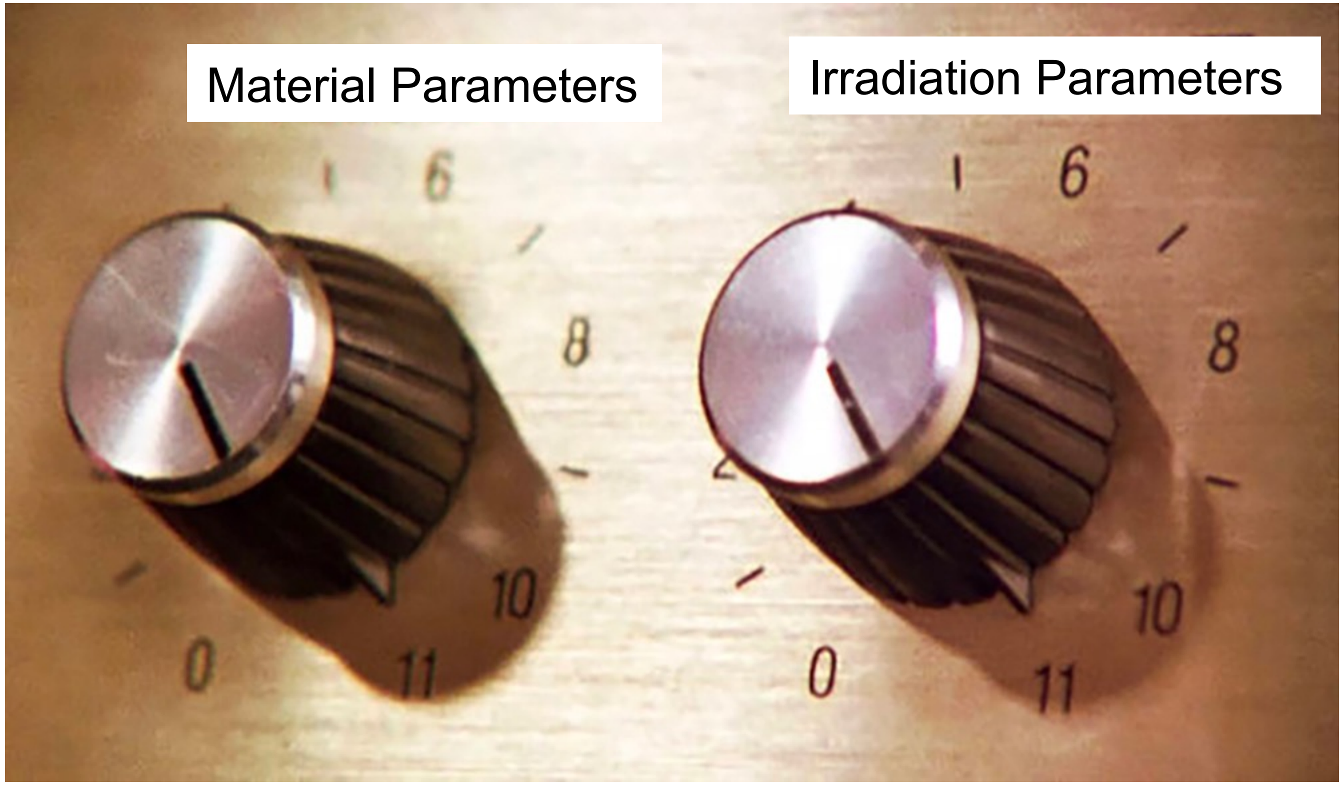
- Ostwald AND Inverse Ostwald ripening can be accelerated due radiation:
    A. True
    B. False



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

Take home message



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

Take home message

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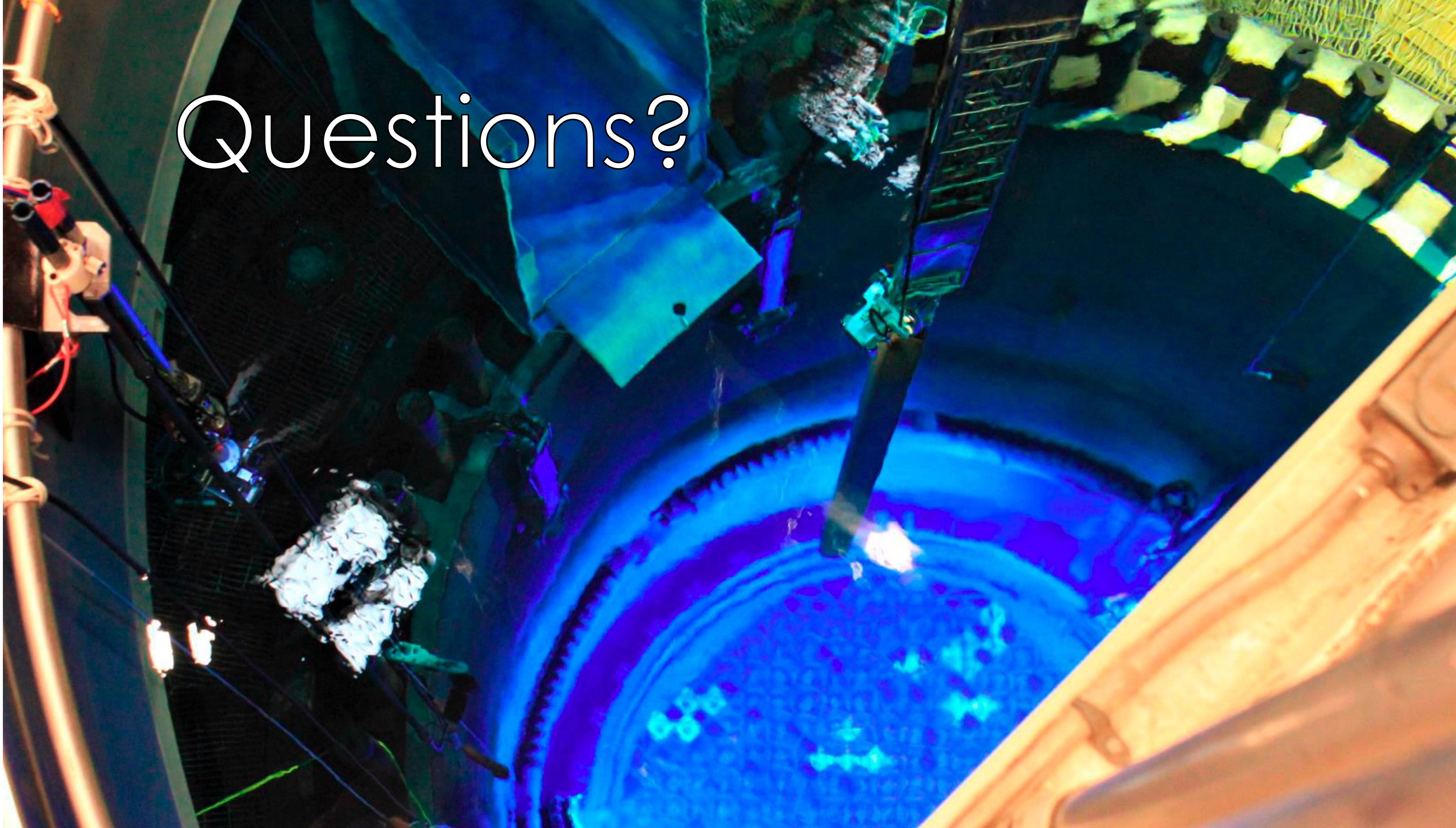
Thank you!


Questions?