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Question (1) Why different cladding/structural materials are required for advanced reactors

* Advance reactor systems operate at much higher operating temperatures
* Higher fast ~~flux~~ neutron fluxes → leading to more radiation damage in cladding and structural materials

* Need to be compatible to different types of coolants other than water ✓ (Na in SFRs and molten salts in MSRs)

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Question (2) Considerations when optimizing the composition for F/M steels

* Precipitation behavior ≠ favorable and/or unfavorable precipitation of phases must be taken into consideration when choosing the composition of a major alloy constituent and solute additions
~~* Corrosion resistance~~
→ Precipitates may enhance or degrade the mechanical properties of steel

* Corrosion resistance : Minimum of compositions of some elements such as Cr or Al may be required to achive good corrosion resistance (by forming a protective passive film)

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Question (3) Why Ferritic Steels swell less than Austenitic Steels?

* The relaxation volume for interstitial in ferrite is larger than in Austenite
  # Therefore, in ferrite, interstitials repel other interstitial & attracts vacancies (recombination) ✓

* Vacancy migration barriers are lower in ferrite
  # more mobile vacancies in ferrite ✓ tend ~~make~~ to recombine more with interstitials

* Interaction between solute & dislocations make them strong ✓ sinks for vacancy

* Vacancies tend to bind more with carbon ✓ in ferrite than in Austenite (because C-Vac binding energy in ferrite is about twice that in austenite)

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Question (4) Role of oxide particles in ODS steels

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* Y_2O_3 / $Y_2Ti_2O_7$ stabilize ferrite ✓ at high temperatures giving high T strength (prevents phase transformation from α to γ)

* The oxide particles also improve swelling ✓ resistance, and creep resistance

-defect sinks, dislocation obstacles

Question (5)

Advantages of Ni alloys   8/8

* Compatible with water, molten salts and liquid Na
* Excellent corrosion resistance
* High temperature stability

Disadvantages of Ni alloys

* Production of Helium under irradiation leads to He embrittlement
  (from the (n, α) reaction with Ni-58)
* High cost

Improving strength of Ni alloys — precipitation hardening / Solution Annealing

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Question (6) Unique features of conditions in research reactors compared to LWRs

* Operating temperatures are much lower in research reactors

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* Neutron flux is much higher in research reactors
* More operation time under transient conditions in research reactors

- high density fuels, no plenum, plate type fuel, high burnups

Question (7) Why is amorphication a concern in research reactors?

* Amorphization of U_3Si_2 is beneficial to inhibit swelling

-nope

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Question (8) U-Si vs. U-Al 4/6

* U-Si has higher fissile density than U-Al ✓
  ∴ This allows for going to lower U^{235} enrichment. ✓

* Problems of U-Si : # interaction with the matrix ✓ and formation of U-Al-Si phases ✓
  # swelling ✓

Push towards U-Mo

* Higher fissile density ✓ (lower enrichment required) ✓
* Mo is very good in stabilizing the γ phase ✓

Question (9) Swelling in U_3Si vs. U_3Si_2

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* U_3Si swells more drastically ✓
* U_3Si_2 amorphizes which leads to suppressing ✗ the swelling

- both amorphize and swell

the ΔV crystal → amorphous is believed to govern swelling

Question (10) Why γ U-Mo is the dominant Phase in-reactor?

* Fission gas bubbles formed in U-Mo resist the transformation of γ phase to the α-phase (orthorhombic)

- nope

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Question (11)

* The fabrication of U-Mo fuel has to be performed (casted) above the liquidus line - obviously

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* Then quenched to temperature below solidus line - again, obviously

- Mo segregation, Mo solidifies first

Question (12) Evolution of fission gas bubbles in U-Mo as function of burnup

* In the beginning (at low burnup), gas bubbles of small size and high number density are formed ✓

* The formed tiny gas bubbles form a superlattice that is ~~dist~~ distinct and often observed in U-Mo fuels ✓

* As the burnup increases → recrystallization occurs ✓

* Recrystallization results in grain refinement with more grain boundaries created ✓

* At that point, breakaway of swelling occurs where ✓ swelling rate increases

* Fission gas bubbles are observed ~~a~~ along grain boundaries at high burnup ✓

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Question (13) Role of Zr layer in U-Mo monolithic fuels

* Zr layer acts as an interdiffusion barrier between the fuel and the Al cladding ✓

* Typically, Zr layers have thickness of 25 μm ✓
~~(The [illegible] higher~~ (The longest recoil range in the fuel ~9 μm)

6/6 - prevent interaction layer growth

Question (14) Why is Al suited for research reactors & not in LWRs?

* At the low operating temperatures in research reactors, Al has excellent properties:
  - excellent corrosion resistance due to formation of protective passive layer of Al_2O_3 ✓
  - Doesn't have a ductile to brittle ✓ transition at low temperature
  - Good mechanical properties at ✓ low temp (ductile)
  - swelling resistant & creep resistant ✓

* In addition, Aluminum is cheap, and also easily fabricated (machinable, castable, and weldable) ✓

* However at high temperatures (in the range of LWR operation):
  - ~~Very~~ Close to the melting point of Al ✓
  - creep and swelling behavior ~~[illegible]~~ degrades at high T ✓
  - becomes more susceptible to corrosion 8/8