1 Advanced reactor systems are characterized by high burnup and/or high temperatures which ~~badly aff~~ harshly affect usual cladding materials causing significant swelling and mechanical-property degradation. So, cladding materials that are creep resistant at high T and undergo minimal swelling (which is enhaced by T) are required.

8/8

Mohamed

100

2 ~~- High Cr leads to the f~~
~~- low Cr promotes f~~

8/8

Cr:
- High Cr promotes the formation of δ-ferrite
- Low Cr reduces oxidation/corrosion resistance.

Si:
- High Si promotes the formation of δ-ferrite
- Low Si also reduces oxidation resistance.

* High carbon content promotes the formation of $M_{23}C_6$ along the grain boundaries which embrittles the material.
* Low C content promotes the formation of moncarbides which are preferrables due to their smaller size in ~~p~~ increasing the strength of material.
* Thermo-mechanical processes during fabrication also affect the microstructure and properties.

$\boxed{3}$ 1) Due to their structure (BCC) they have more space to accomodate fission products. → doesn't have fission products

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2) Dislocations and solutes act as strong sinks for vacancies which limits their migration to void embryos.

3) Interstitial volumes are larger in ferritic than in ~~austent~~ austenitic steels → more strains around interstitials, which attracts vacancies to ~~the~~ reduce the stress state.

4) Vacancy migration barrier is less in ferrites than in austenite which enhances defect recombination.

5) Martensitic laths act as sinks to FP gases.

6) Carbides act as traps for vacancies due to the large C-vacancy binding energy

$\boxed{4}$ - Oxide particles increase the strength of ODS steels → act as ~~and~~ obstacles to dislocation climb and glide which also ~~increep~~ increase the creep resistance.

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- Yttria helps stabalize the α ferretic phase → otherwise heat treatments would gives us austenites. The mechanism is that oxides particles impede the motion of phase interfaces.

[5] Advantages:

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- High strength
- High creep resistance especially at high T making them suitable for fact reactor applications.
- High corrosion resistance.

Disadvantages:

- Ni-59 interacts with neutrons to produce He (n,α reactions) which leads to He embrittlement of the alloys.

~~He~~ This is due to its high neutron absorbtion cross-section.

* Strength is improved in Ni alloys through the formation of intermettalic phases that precipitate leading to increasing strength of the alloy. Intermetallic phases like Ni_3Nb ~~and Ni_3Si~~, where Fe and Cr can substitute for Ni.
* Solid-solution strengthening ~~is~~ through addition of solutes atoms like Fe, Cr, Nb, Mo.

Note that the neutron absorption cross section of (n,α) reaction in Ni decreases with increasing ~~temp~~ neutron energy → not a significant issue in fact reactors.

6 Rearche reactors:

- Lower temperatures (< 100°C)

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- Higher ~~neutron~~ fission density (the goal is neutron production not power production)

- Plate-type fuel designs with no plenum or gap compared to rod-type designs in LWRs.

- The need for higher uranium content and higher fissile density which make the use of intermetallic fuels necessary (metallic uranium is not usable due to ~~that~~ its anisotropic features).

7 The high fission rate combined with the low temp (which impedes recombination due to the low mobility of defects) makes irradiation of all intermetallic fuels in ~~res~~ research reactors leads to amorphization of the fuel and its interaction layer with the cladding.

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- Amorphization leads to increasing atomic mobility of fission products (especially gases) which makes phenomena like blistering an issue during fabrication and operation of the fuels (and swelling in general) especially that there are no gap of plenum in plate-type fuel designs.

- U-Mo doesn't amorphize

$\boxed{8}$ – U-Si has more U density than U-Al. [benefit]

– U-Si phase (U_3Si) undergoes larger and unstable FG swelling wheras U_3Si_2 undergoes moderate and stable FG swelling. In contract, FG swelling is not a concern in U-Al because the bubble that form are so small to be detectable and Xe ~~is~~ has a large solubility in U-Al and remains in solution. [Drawback]

– To use LEU within the same volume of the fuel, higher density of U ~~were n~~ is needed (higher than that of U-Si) ~~to~~ compensate for the reduction in enrichment. For this reason, the U-Mo fuel (which has higher U density than both U-Al and U-Si) was pursued in both dispersion and monolithic designs.

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$\boxed{9}$ – U_3Si swelling is ~~larage~~ large and unstable and undergoes fast breakaway: ~~where~~ The bubble are large and irregular.

6/6

– The swelling in U_3Si_2 is smaller and more stable with no breakaway and the bubble sizes are smaller.

– This is at low temps. At high T, the swelling of U_3Si_2 is similar in character to that of U_3Si and its stability is lost.

$\boxed{10}$ 1) The Mo in concentration 6–12 wt % can stabilize the gamma phase, making it a metastable state that can be quenched.

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2) Radiation further stabilizes the gamma phase by breaking the gamma' phase upon forming.

– The critical fission density rate is the rate that just balances the thermodynamic driving force for transforming $\gamma \rightarrow \gamma'$.

11 In the existance of ~~sol~~ a gap in the solidus - liqudus ~~pt~~ line, Mo-rich phases solidify first before Mo-deficient phases. The microstructure of U-Mo fuel ends up having Mo-rich phases surrounding by ~~Mo-deplect~~ Mo-depleted phases at their boundary.

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Increasing the homogenization temp. reduces this Mo concentration gradient.

12 - At low burnup, a fission gas superlattice forms. This superlattice gets destroyed later.

10/10

- Increasing the burnup we start with small bubble at grain boundaries. Then, as grain refinement proceeds, more grain boundaries are formed and bubbles coalesce along those new grain boundaries.
- At high burnup, when the grain refinement is near completion, the bubbles are formed ~~ato~~ nearly homogenously over all the fuel praticle.
- Interaction layers between U-Mo and Al have more porosity and less density (due to the formation of >4 (U, Mo) Al_x phases) which makes them filled with fission gas bubbles.

[13] The Zr layer is an interdiffusion barrier to prevent the formation of an interaction layer between U-Mo and Al cladding.

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This interaction layer has $(U,Mo)Al_x$ phases with $(x>4)$ which has low density and contain much ~~pros~~ porosity which makes them a perfect spot for fission gas bubble formation.

~~This IL can be eliminated by~~:

~~1) Changing the matrix to~~

~~2)~~

This IL formation is driven by thermally activated diffusion and irradiation-enhanced diffusion.
So, to prevent its formation:

1) Remove Al and use other ~~cladding~~. matrix.
2) Remove the matrix altogether and introduce interdiffusion barrier coupled with a monolithic fuel design.

$\boxed{14}$ Al is soft (low elastic modulus), cheap, available, machinable, manufacturable, have good corrosion resistance against water (~~fam~~ forming passive alumina layer) and against hydriding, and has low melting point.

Its low melting point makes it unsuitable for LWR application, but because the temperature in research reactors is already low (<100 °C) and due to its economic and manufacturing benefits, it is very suitable for ~~rea~~ research reactors.

Also, it is susceptible to creep at T > 150 °C.

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