92 + 4 = 96

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NE 795-010 Advanced Reactor Materials and Materials Performance

Exam 4

The associated point values provide an indication of the expected thoroughness of response.

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1. What is unique about the reactor conditions inside research reactors, including geometry, compared to LWRs? (8 pts)
2. Why is amorphization of concern in research reactors? (8 pts)
3. What are benefits and drawbacks of USi fuel compared to UAl fuel? Why is there a push towards UMo fuel? (10 pts)
4. Describe the differences in U3Si and U3Si2 swelling. (6 pts)
5. The gamma phase of UMo is not the thermodynamically stable phase at research reactor temperatures. Why is this phase the dominant phase in-reactor? (6 pts)
6. What effect does the solidus/liquidus gap have on fabrication of UMo fuels? (6 pts)
7. Discuss the evolution of fission gas bubbles in UMo fuel as a function of burnup. (12 pts)
8. What is the role of the Zr layer in UMo monolithic fuels? What are the consequences of adding this layer? (8 pts)
9. Why is Al ideally suited for the research reactor environment when it is unable to be used in LWRs? (8 pts)
10. What are some considerations when optimizing the composition for F/M steels? (8 pts)
11. Why do ferritic steels swell considerably less than austenitic steels? (10 pts)
12. What role do the oxide particles play in ODS steels? What properties do ODS steels specifically display that improve upon F/M steels? (10 pts)

Ans. to the ques. no. 1 7/8

The perpose of research reactor(RR) is to generate nutron not power which is the main ✓ perpose of the light water reactor(LWR).

Operating temperature of RR is smaller ✓ than the LWR, 150°C compared to 300°C.

Usually research reactor has a simple pool type cooling system, whereas LWR has more vigorous cooling system. - not necessarily

Fuels used in RR usually has a plate
(disporsed or monolithic)
-type construction, for LWR condition fuel is used as pellet form.

Because of non-proliferation low enrich uranium is used in RR. So U-Al, U-Si, U-Mo based fuel is used. In LWR UO_2 is used. -high power density

Ans. to the ques. no. 2

6/8

In research reactor, due to neutron irradiation (boambarding), point defects are formed. But as operating temperature is low, these point defects could not be mobalized, specially the vacancies. As a result, recombination is not occured to heal the radiation damage and large cluster could not formed. Single points defects remain within the fuel matrix which leads to amorphization. -effect of amorphization?

10/10

Ans. to the ques. no. 3

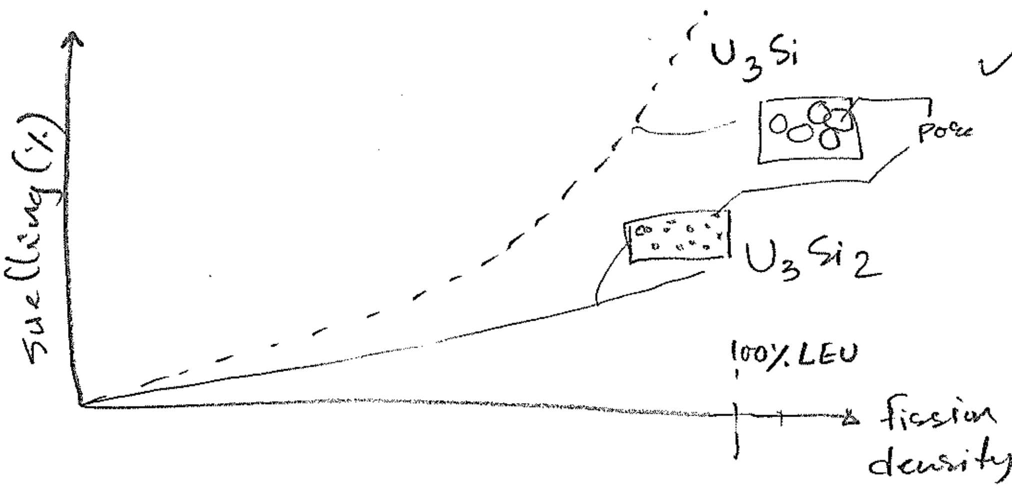
In USi fuel system, density of U is higher than the U-Al system. For research reactor to maintain LEU, density of U should be higher.

The problem of U-Si system over UAl system is the presence of Al matrix. Both system has dispersed fuel in Al matrix and cladding. In U-Si system U(SiAl)3 interaction layers are formed, which is a detrimental site to form pores and bubble. Also, U-Al system amorphize earlier, which leads early swelling.

Moreover blistering threshold temperature in U-Al system is lower, which means early failure.

Because of higher U density there is a push towards U-Mo system. Also, U-Mo has a more stable bcc crystal structure.

Ans. to the ques. no 4 6/6



U_3Si system shows higher swelling rate than the U_3Si_2 system. ✓

Because of the presence of additional Si-Si bond in U_3Si_2 system, there is less volume to deform the U_3Si_2 crystal which leads to higher viscosity. ✓ Higher viscosity results in lower diffusion rate. As such smaller pores or bubbles are formed in U_3Si_2 system compared to U_3Si system. ✓

Ans. to the ques. no. 5 6/6

γ-UMo phase can be decomposed into αU and γ'-U_2Mo. phase at 565°C, which temperature can be attained within research reactor fuel system. But still this phase (γ) is stable because of radiation damage. If reactor is operating more or equal to critical fission rate, then decomposition of phases is balanced out with reverting back to the γ phase. Addition defects formed in radiation damage helps to stabilize the system at higher energy stage (γ).

Ans. to the ques. no. 6 6/6

The solidus / liquidus gap in U-Mo is a function of Mo contentent. More the Mo content, lesser is the solidus / liquidus gap. As a result, during cooling

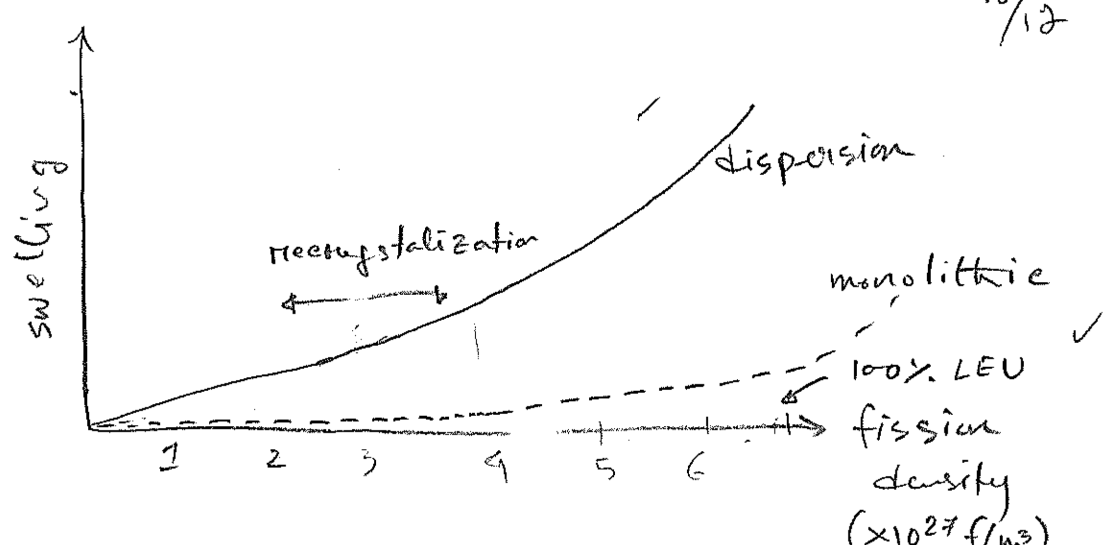
Mo rich phase will be solidified earlier, forming a Mo-rich phase in a Mo-lean matrix.

Usually Mo-lean phase is more formed near grain boundaries, and they are more prone to phase decomposition. Also U distribution becomes heterogenous due to different Mo distribution.

When cooling rate is lower more homogenous U-Mo system could be attained.

Ans. to the ques. no. 7

10/12



Swelling in UMo fuel system

Swelling in U-Mo system (dispersion) can be described via three phases

① at low burnup ($< 2\times10^{27}$ f/m³) no visible in an SEM bubbles are formed, and grain refinement starts

② at intermediate burnup ($2\times10^{27} <$ fission density $< 4\times10^{27}$) both grain refinement and formation of bubbles along the grain boundary occurs. Swelling rate is proportional in a linear function to the burnup.

③ At higher burnup ($> 4\times10^{27}$ f/m³) bubble forms both in inter and intra graunular space and can be correlated quardrically with burnup up.

- fission gas superlattice at low BU suppresses swelling

In monolithic type U-Mo system, swelling is delayed till 4×10^{27} f/m³ burnup, as grain refinement and formation of bubbles at interaction layer (IL) and small amount at grain boundary happens. With burnup more bubble is formed near IL. At more than 100% LEU burnup ($> 8.4\times10^{27}$ f/m³)

IL is dittached from the matrix and IL buldged. ✓

<u>Ans. to the ques. no. 8</u> 8/8

Zr layer in UMo monolithic fuels is added as a barrier between ✓ Al cladding and U-Mo fuel matrix.

When Zr layer is added detrecmental Al rich U-Al layer ✓ is not formed. But some other phases based on U-Zr ✓ system on fuel side and Zr-Al-Si system of cladding side is formed. No effect of these secondary phases are not known yet. ✓

Ans. to the ques. no. 9 8/8

Al has a very high thermal conductivity and easy formability, though it has a lower melting point. As research reactors(RR) operate at a lower temperature, Al will not reach its melting point. Al is a good solution of cladding in RR at a lower cost.

In contrast to this, Al is not suitable in LWR because of its lower melting point and being very prone to high temperature aquaus corrosion.

Ans. to the ques. no. 10 8/8

Some considerations while optimizing F/M steel:

1. increase in Cr increase oxidation resistance, also increase resistance in swelling.
2. increase in Cr increase in DBTT. which makes steel more prone to

radiation embrittlement - above 9G

3. Increase in Ni will reduce the reduction in toughness. ✓

4. B could be added for grain boundary strengthening. ✓

5. In the boundary of the lath (martensite) $M_{23}C_6$ precipitate is undesirable compared to smaller MX precipitates. Also higher C - content is required to maintain martensite phases. ✓

Ans. to the ques. no. 11 8/10

Reasons of ferritic steel swells less than austenitic steel :

1. Ferritic steel has bcc crystal structure and austenitic ✓ steel has fcc. Interstitial in bcc phase larger strain field compared ✓ to fcc. This larger strain field repels the other interstitials and ✓ attracted more vacancies.

As a result there is more probalities of recombination.

2. Migration energy of vacancies is about one-third of migration energy of vacancy in fcc lattice. So, vacancy is more mobile in bcc lattice.

3. Finally interstitials of bcc crystal have larger binding energy with dislocation which forms a larger sink for vacancies.

As vacancies could not be clusted at a rate compared to fcc crystal, less amount of bubbles are formed, which leads to less swelling in bcc ferritic phase

- C-vacancy binding is higher in ferrite
- Solute atoms promote sinking of vacancies to dislocations

9/10

Ans. to the ques. no. 12

Oxide particles in ODS steels both as a precipitation hardening species and vacancy sink. As a result ODS steel has less swelling and more hardness than F/M steel.

Oxide precipitate increase the yeild stress of the F/M steel, by hindering dislocation motion via precipitate cutting and wrapping mechanism. Also dislocation climb and glide is hindered resulting in higher creep resistance.

Also transition temperature of γ (austenitic) to α (ferritic) phase is reduced, which make ferritic phase presence more easier.

→ improving high temperature mechanical properties such as creep resistance