22.251 Systems Analysis of the Nuclear Fuel Cycle
Fall 2005
PROBLEM SET #6

1) Explain the behavior of the attached k-H/HM and B_1-H/HM plots in terms of basic reactor physics phenomena and principles. The plots show the initial effective (at zero burnps) and the reactivity-limited single batch burnup, B_1 as a function of the ratio H/HM of hydrogen to heavy metal atoms. The curves are all based on the standard Westinghouse 17x17 fuel geometry and dimensions. The variations in H/HM were obtained by arbitrarily changing the water density in CASMO. Address the dominant causes in each of the three regions designated, with emphasis on slope, minima and maxima.

2) What are the implications for operation in region (3) rather than (2) in Figure1 for
   - Core compactness
   -Reactivity control during a loss of flow and a loss of coolant accident

3) Consider the engineering aspects of the core design, where would you expect to draw lines in Figure 1 to represent heat transfer limiting lines for steady state operations.

4) Would you want the reactor to be designed at the point of maximum $B_{,}$ between (2) and (3)? Explain any considerations that you will have to consider

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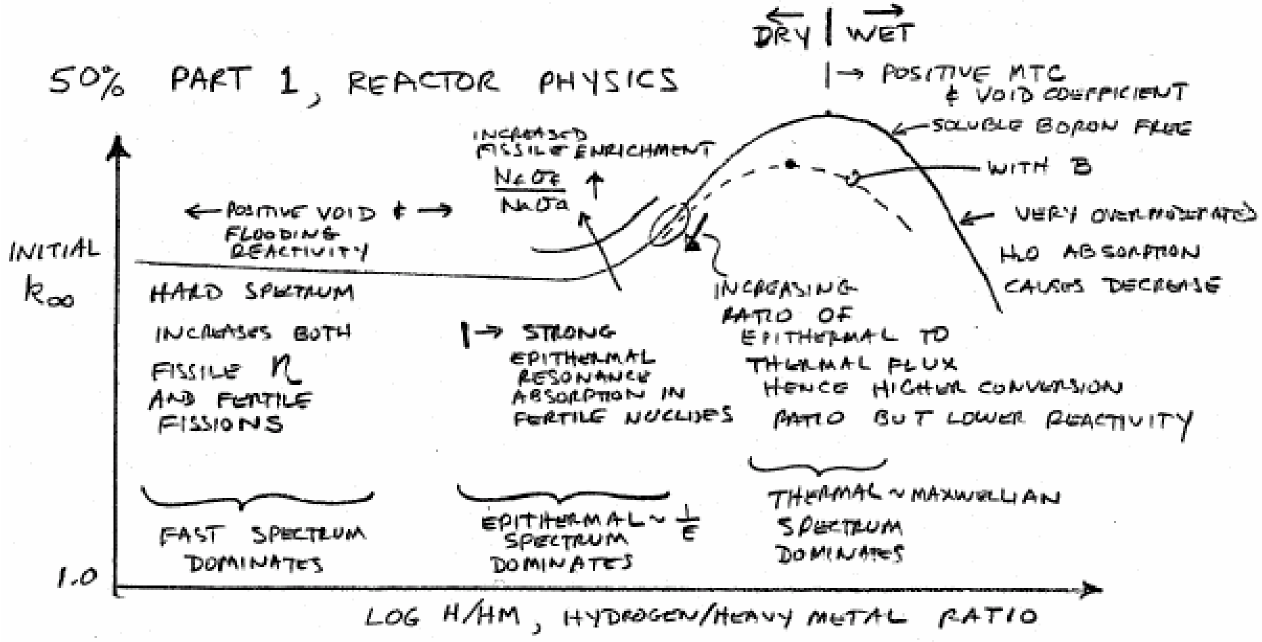
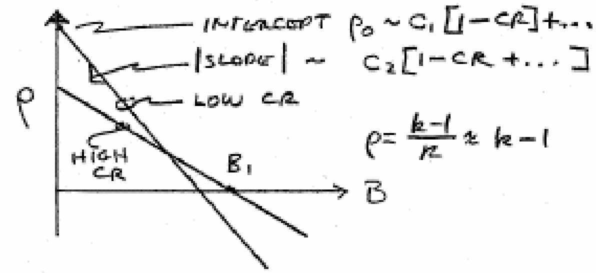
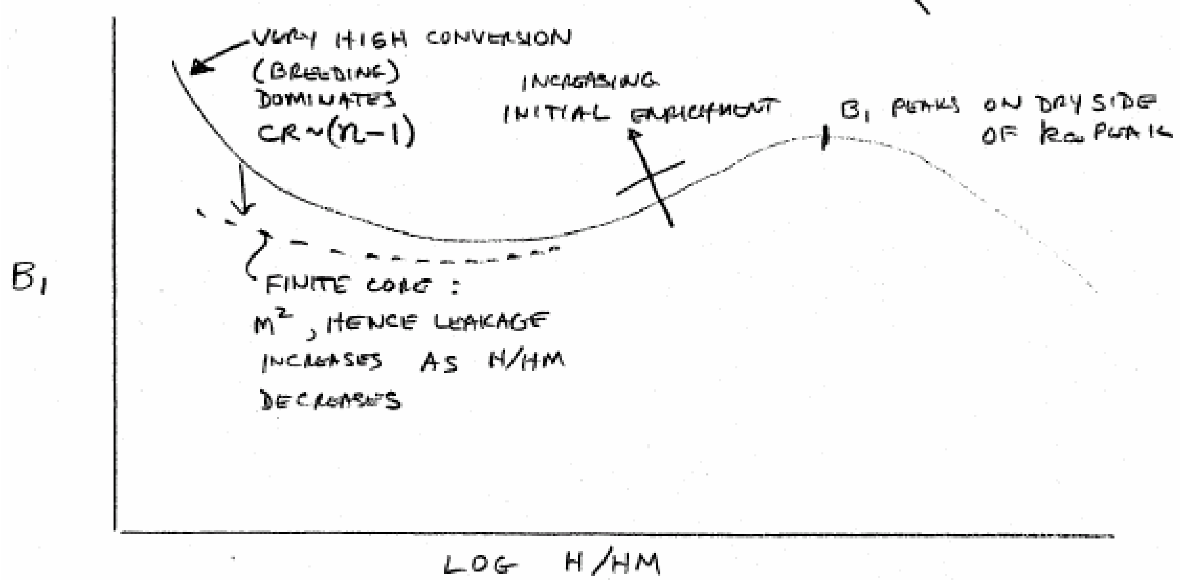
22.351 PROBLEM SET No 5, SPECIMEN SOLUTION

50% PART 1, REACTOR PHYSICS



B_1 IS SOMEWHAT SIMILAR CONSIDERING $B_1 = \frac{\rho_0}{(d\rho/dB)}$ AND RELATION OF NUMERATOR & DENOMINATOR TO CONVERSION RATIO





2)

Operating in region 3 rather than region 2 would require a larger amount of moderator. Assume this is achieved by increase the volume of water (otherwise, for example, solid hydride can be introduced as moderator), thus larger core volume is required to hold the moderator due to the very low compressibility of water.

During LOFA, the temperature of moderator increases, since region 3 is over-moderated, the positive MTC in region 3 could introduce a positive reactivity change. In case of LOCA, the moderator removed could cause a reactivity insertion. If prompt critical is achieved, a rapid power increase in the fuel pin could comprise the cladding integrity and even release of radioactivity. This increases the difficulty of reactivity control.

Therefore, operating in region 3 is not desirable.

3)

We consider 3 ways to change H/HM:

(1) If the change is due to changing the fuel pin diameter

as $d\uparrow$, H/HM $\downarrow$, q' is fixed $\Rightarrow q''\downarrow$

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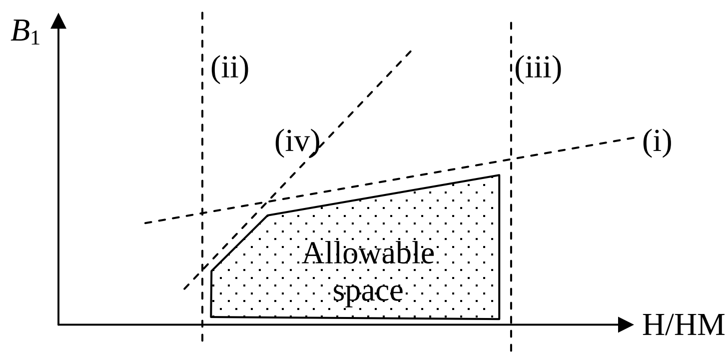
(i) For the same q', the fuel average temperature is the same and fission gas release is about the same. However, as H/HM $\downarrow$, the fast spectrum component grows and the damage to cladding accelerates, hence lower burnup will be tolerated.

(ii) As H/HM $\downarrow$, higher velocity of coolant is needed to maintain cooling. At some low levels there will be a limit due to velocity limitation (sonic for stream, vibration for both vapor and liquid, cavitation for liquid)

(iii) As $q''\uparrow$, the $(T_{clad} - T_{coolant})\uparrow$. Also DNBR $\downarrow$ if the coolant velocity is decreased to keep T_{exit} high, then q''_{DNB} will also decrease, which aggravates the situations, and leads to a limiting H/HM.

(iv) As $B\uparrow$, more H/HM is needed to ensure cooling during a loss of flow or coolant accident & avoid clad overheating.



(2) If the change in H/HM is due to smaller number of pins of the same diameter, then

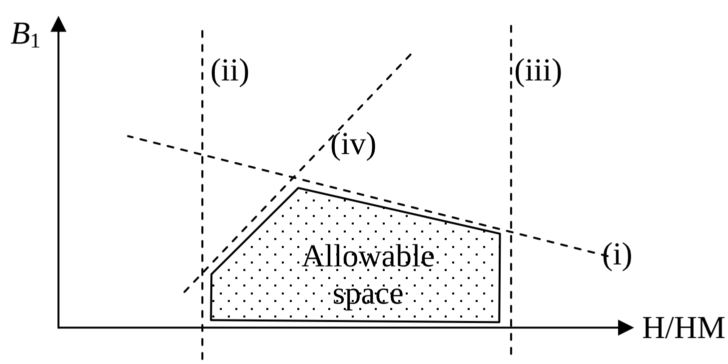
as $n\downarrow$, H/HM $\uparrow$, $q'\uparrow$ and $q''\uparrow$

(i) Since $q'\uparrow$, fission gas release $\uparrow$ and for the same cladding there is a lower allowable internal pressure, hence a limit in burnup

(ii) There is a limit on the low end of H/HM due to limit on velocity of coolant

(iii) Limit on high H/HM due to DNBR consideration

(iv) There is a limit on allowable low H/HM as $B\uparrow$



(3) If the change in H/HM is due to using annular fuel, then

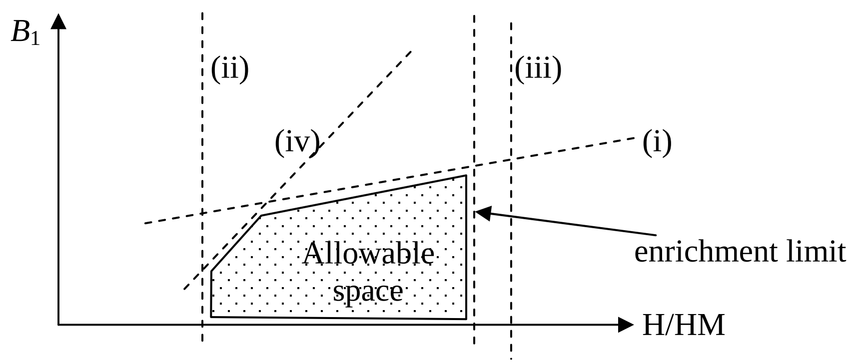
as H/HM ↑, pellet thickness ↓, q' and q'' fixed.

(i) As pellet thickness ↓, more burnup is tolerated due to lower fuel temperature & more free volume in fuel pin. But, too thin a pellet will be limited by allowable enrichment as well as local burnup due to extreme local burnup. For large void volume a filler is needed to prevent crumbling.

(ii) Limits on low end of H/HM due to coolant velocity needs are pushed to higher values since coolant space limits imply higher values of H/HM.

(iii) Limit on DNBR is also moved to higher values of H/HM since pin diameter & q' are not changed. But higher H/HM than current PWR would not be tolerated.

(iv) The thermal stored energy is smaller hence lower H/HM values can be tolerated for a given burnup.



4)

Choosing an operating point for the PWR need consider safety, security and economic aspects.

There is very little margin between the highest burnup point and region 3 where over-moderations occurs. As explained in 2), this would be unsafe to introduce positive reactivity during LOCA or LOFA accident.

In figure 1 and figure 2, enrichment is varied in a wide range from 4.5% to 19.5%, a higher enrichment would favor a higher burnup. This has the advantage to increase the fuel economy, but from non-proliferation consideration, high enrichment would not be allowed as 5% limit is set by NRC currently. Even from economic point of view, high burnup doesn't always mean low fuel cost. The high burnup may increase the enrichment cost. Although waste amount per unit energy generated is reduced, the heat load and radioactivity might be high for the high burnup fuel. This actually increases the difficulty in geological deposit and/or reprocessing.

Thus operating at a maximum burnup may not be a good choice.