Fuel Performance

NE 591

Last Time

- The heat equation can be solved using numerical methods
  - Explicit: forward Euler – uses current state
  - Implicit: backwards Euler – uses current and future state
- Spatial derivative solution methods divide the domain up into smaller pieces
  - Finite difference
  - Finite volume
  - Finite element
- Each discretization has strengths/weaknesses
- Finite element is primary method for high fidelity fuel performance codes

Thermal Conductivity

- Knowledge of the thermal conductivity of the fuel, gap, and cladding is essential to determine the temperature distribution and transient thermal response
- Sintering creates a porous oxide with about 95% theoretical density
- The pores provide space to accommodate fission gases, and thus reduce swelling, but diminish the thermal conductivity
- Additional porosity develops from fission gas accumulation
- Porosity will degrade thermal conductivity
- Approximations for that degradation can be developed based upon a parallel thermal resistance framework
- This framework accounts for porosity volume, assuming that the pores are approximately cubic
- If we assume that the thermal conductivity of the oxide is much larger than the k_{th} of the pore, then:

$$\frac{k_f}{k_{ox}} = 1 - P^{2/3}$$

- where k_f is the effective therm. cond. of the fuel, k_{ox} is the therm. cond. of the oxide, and P is the porosity

Thermal Conductivity

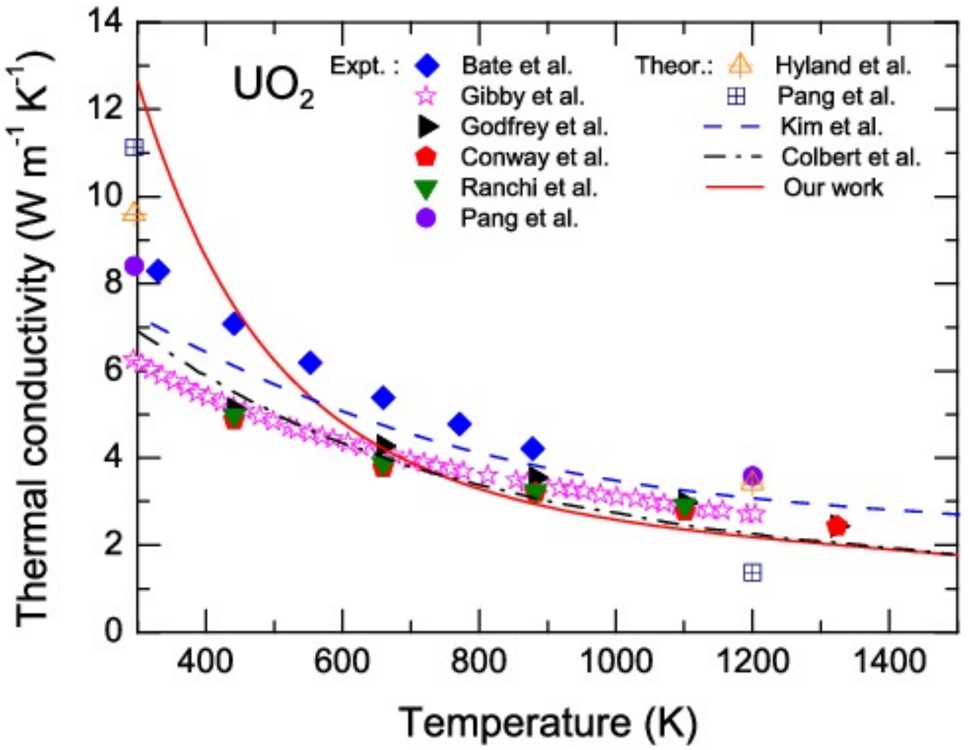
- Typical thermal conductivity of UO2 varies as:

$$k_{ox} = \frac{1}{A + BT}$$

- A=3.8+200xFIMA (cmK/W)
- B=0.0217 (cm/W)
- Neglecting porosity, the temperature at the fuel centerline and fuel surface are related by:

$$\frac{1}{B}\ln\left(\frac{A + BT_0}{A + BT_s}\right) = \frac{LHR}{4\pi}$$

- Solving the heat conduction equation with temperature-dependent k_{th} requires numerical methods



Example

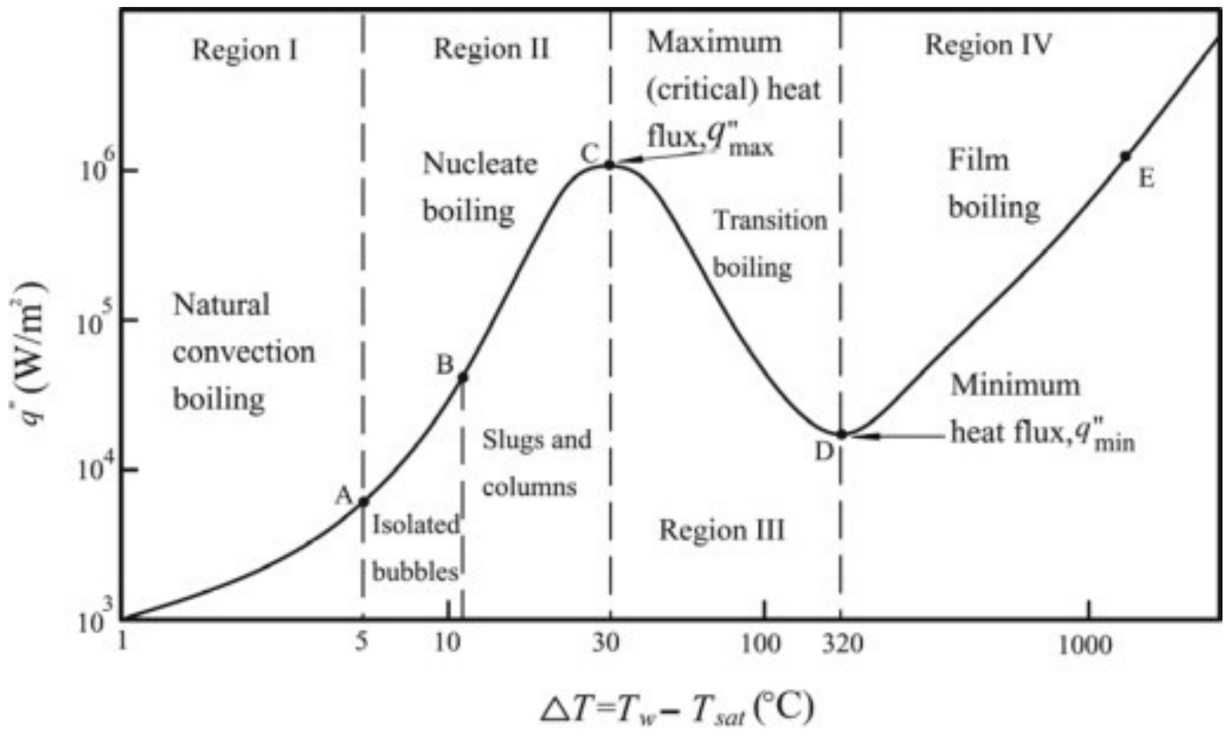
Operational Limits

- Thermal limits are prescribed for normal operation and accident conditions, with the goal of avoiding fuel damage
- Operational limits provide an envelope under which fuel failure will not occur
- LHR limits
- Centerline temperature limits
- Pellet-Clad Mechanical Interaction Limits
  - will cover later in semester

Critical Heat Flux

- As the outer surface of a fuel rod increases, the mode of heat transfer changes
- A boiling curve can be determined experimentally by increasing the temperature and measuring heat flux to the liquid
- In the single-phase mode (region I), flux is driven by temperature difference between the outer cladding surface and the coolant

$$q = h(T_{CO} - T_{cool})$$

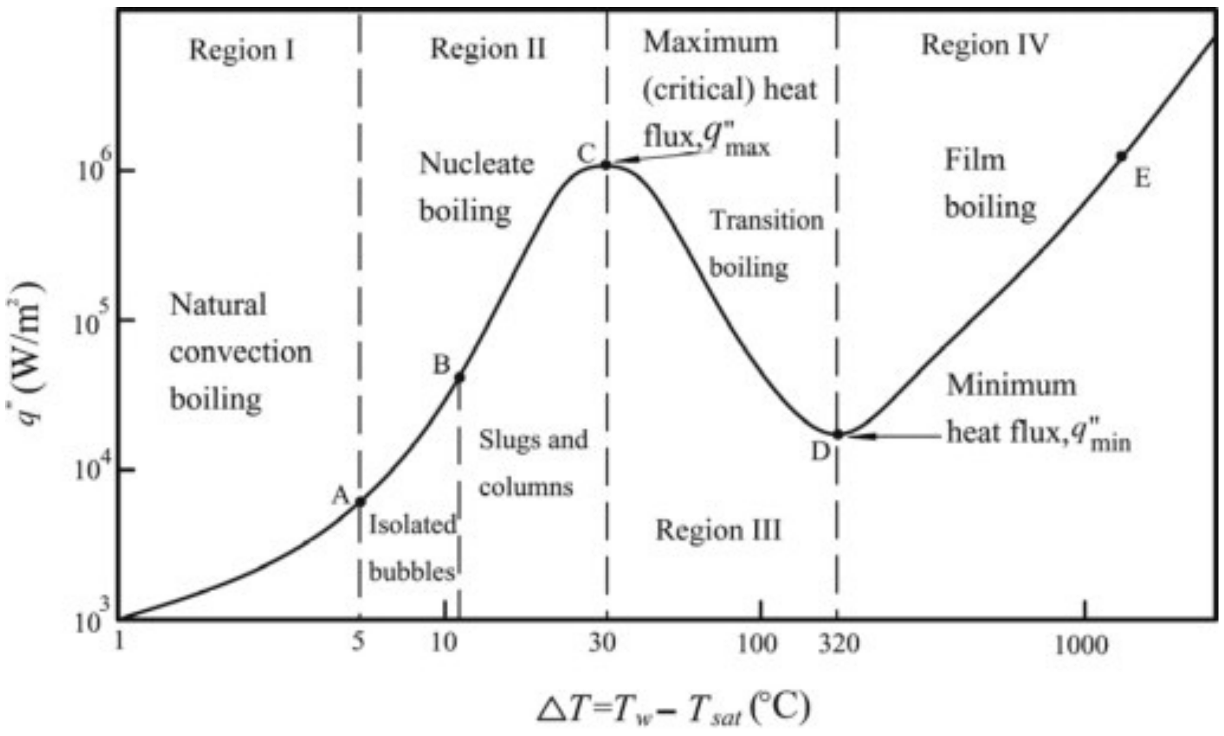


Critical Heat Flux

- The heat transfer coefficient can be determined by the Dittus-Boelter equation:

$$\frac{hd_{eq}}{k_{cool}} = 0.023Re^{0.8}Pr^{0.4}$$

- Re is the Reynolds number and Pr is the Prandtl number, d_{eq} is the equivalent diameter of the flow channel, k_{cool} is the coolant thermal cond.
- We typically assuming a nominal value for h, but in reality, it is temperature dependent

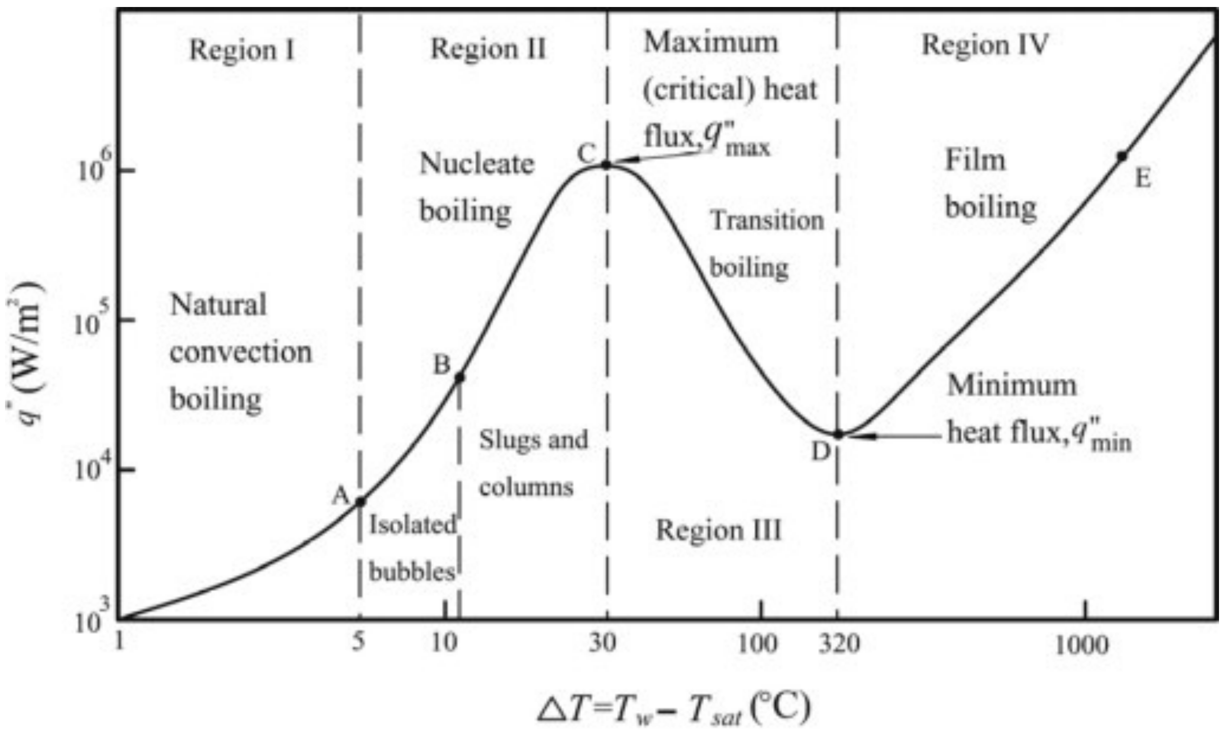


Critical Heat Flux

- At point B, the onset of nucleate boiling provides greater heat transfer to the coolant
- Typical nucleate boiling correlation relating heat flux and temperature is:

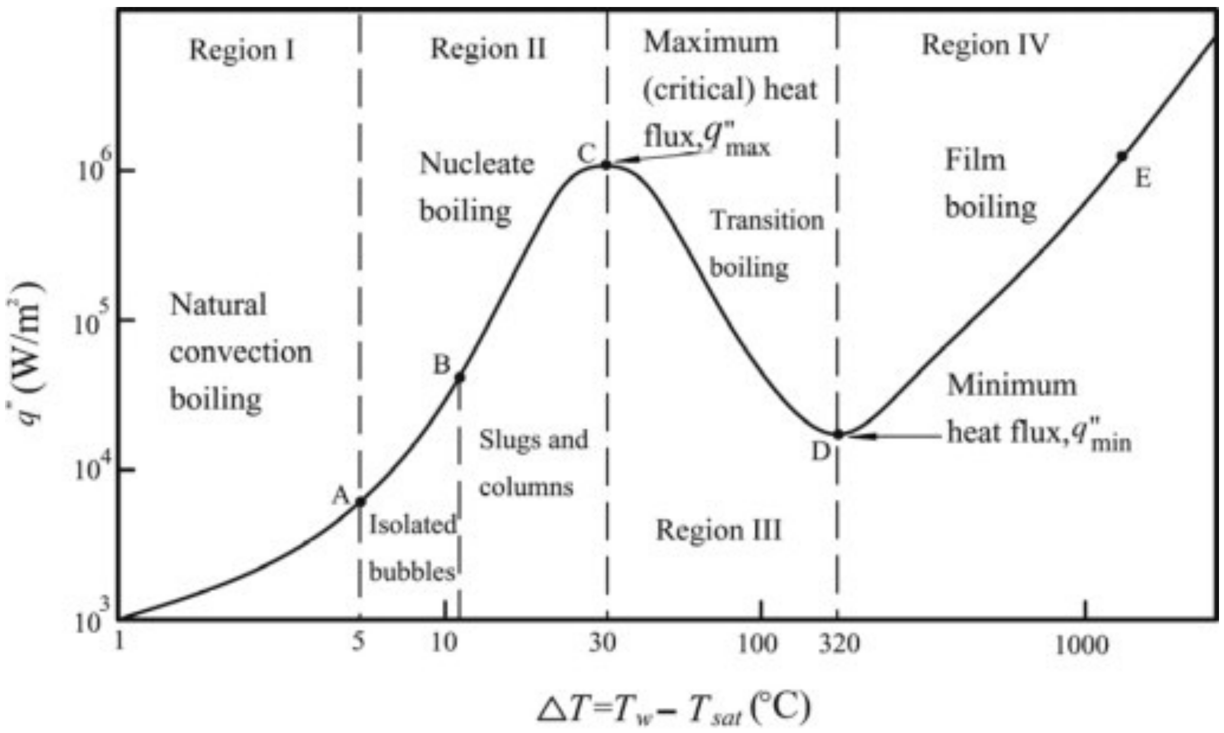
$$q\left(\frac{W}{m^2}\right) = 6(T_{CO} - T_{cool})^4$$

- Heat transfer mechanism is more complex in this region with two distinct phases
- At a critical point, C, the bubbles coalesce, and a continuous film of steam is formed
- Point C is known as the critical heat flux



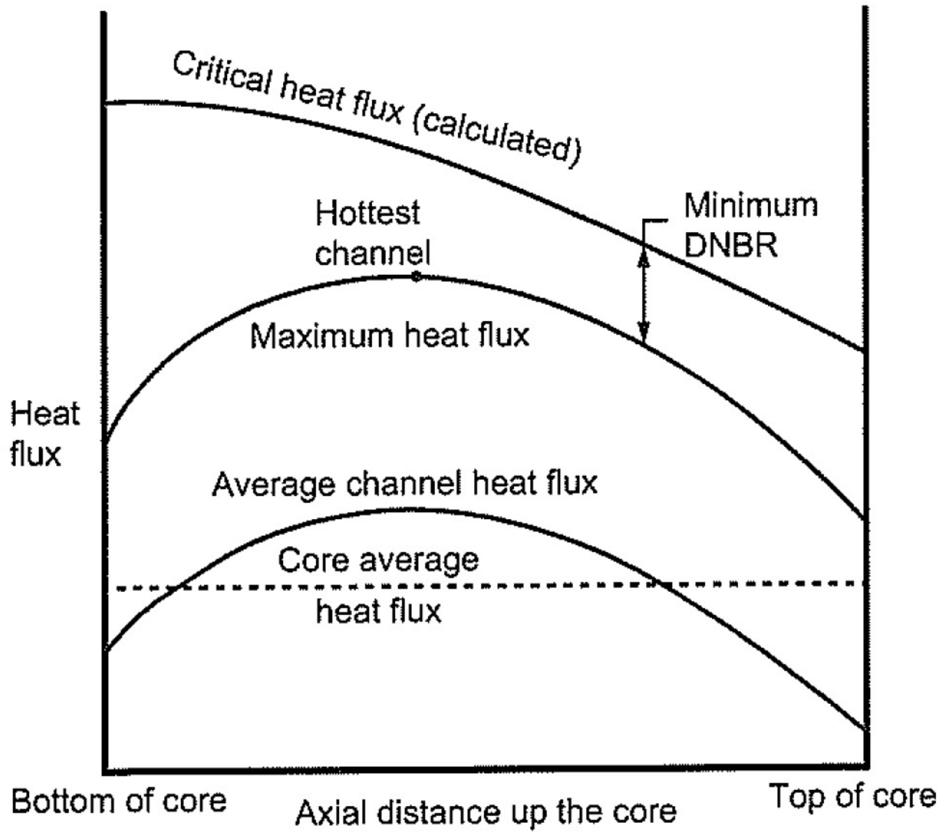
Critical Heat Flux

- Beyond point C the rod is ”coated” in steam and the heat flux is dramatically reduced
- The heat transfer coefficient from cladding to steam is much lower than from cladding to water
- T_{sat} is the saturation temperature, which is fixed for a given pressure, whereas the coolant temperature (T_{cool}) increases
- Beyond point C, film boiling can occur



DNBR

- The departure from nucleate boiling ratio (DBNR) is the ratio of the heat flux that causes dryout (the critical heat flux) to the actual heat flux
- The limits on the DBNR in the hottest channel is 1.15 to 1.3, or a margin of 15-30 percent
- The DNBR is determined by identifying the hottest channel, and the location where the heat flux most closely approaches the CHF
- When CHF is reached, cladding temperature can increase to above 1100 K



Paper Project #1

- Each of you will receive an email with a paper attached by the end of this week
- This will be a critical review of the paper, similar to what we do for QE2, but much shorter
- 15 minute presentation that summarizes what was done in the paper, provides context on why it was done, and reviews what could or should have been done, or could be done next
- Presentations will take place in class on Feb. 15
- All presentations will be submitted via moodle
- Distance students will also submit a recording of their presentation for review
- If in person students prefer to submit recorded lectures, notify me
- All submissions due by end of the day on Feb. 15
- If you have a specific paper that you would like to review and applies to this topic field, present it to me and I will consider it

Problem Session