NucE497: Reactor Fuel Performance

Lecture 21: Final Project Assignment

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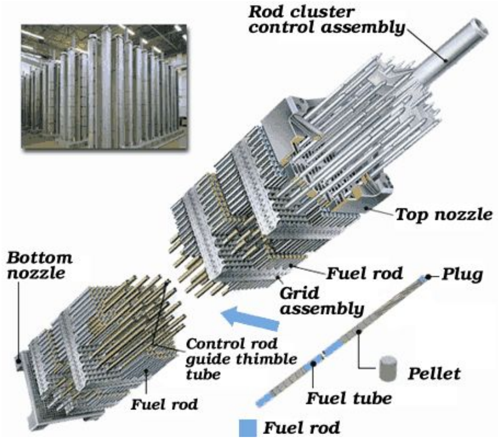
What we discussed so far…

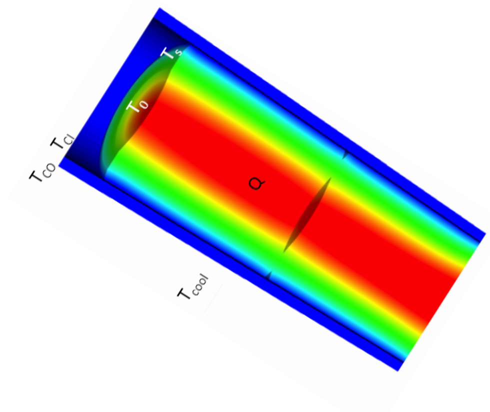
- Module-1: Fuel basics
  - Purpose of the fuel and types of fuel
  - Fission, heat generation, fission products
  - Fuel geometry and the role of cladding
  - Fuel fabrication
- Module-2: Heat transport
- Module-3: Mechanical Behavior



Reference: http://www.world-nuclear.org

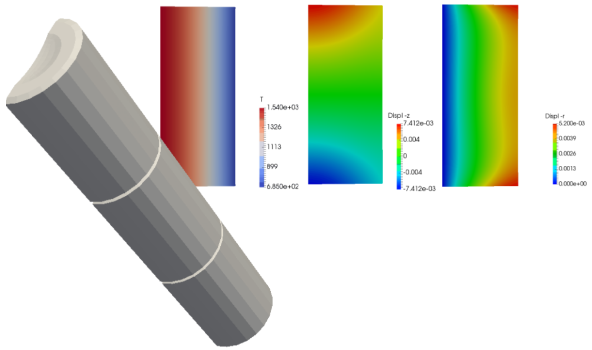
What we discussed so far…

- Module-1: Fuel basics
- Module-2: Heat transport
  - Intro to heat transport and the heat equation
  - Analytical solution of the heat equation
  - Numerical solution of the heat equation
  - 1D solution of the heat equation using Matlab
  - 2D solution of the heat equation using Matlab
  - Coolant temperature change, power generation, and melting
- Module-3: Mechanical Behavior



What we discussed so far…

- Module-1: Fuel basics
- Module-2: Heat transport
- Module-3: Mechanical Behavior
  - Introduction to solid mechanics
  - Thermomechanics, thermal expansion
  - Analytical solutions of the mechanics equations
  - Solving equations in 1D numerically
  - Solving in multiple dimension with FEM
  - Summary of fuel performance codes



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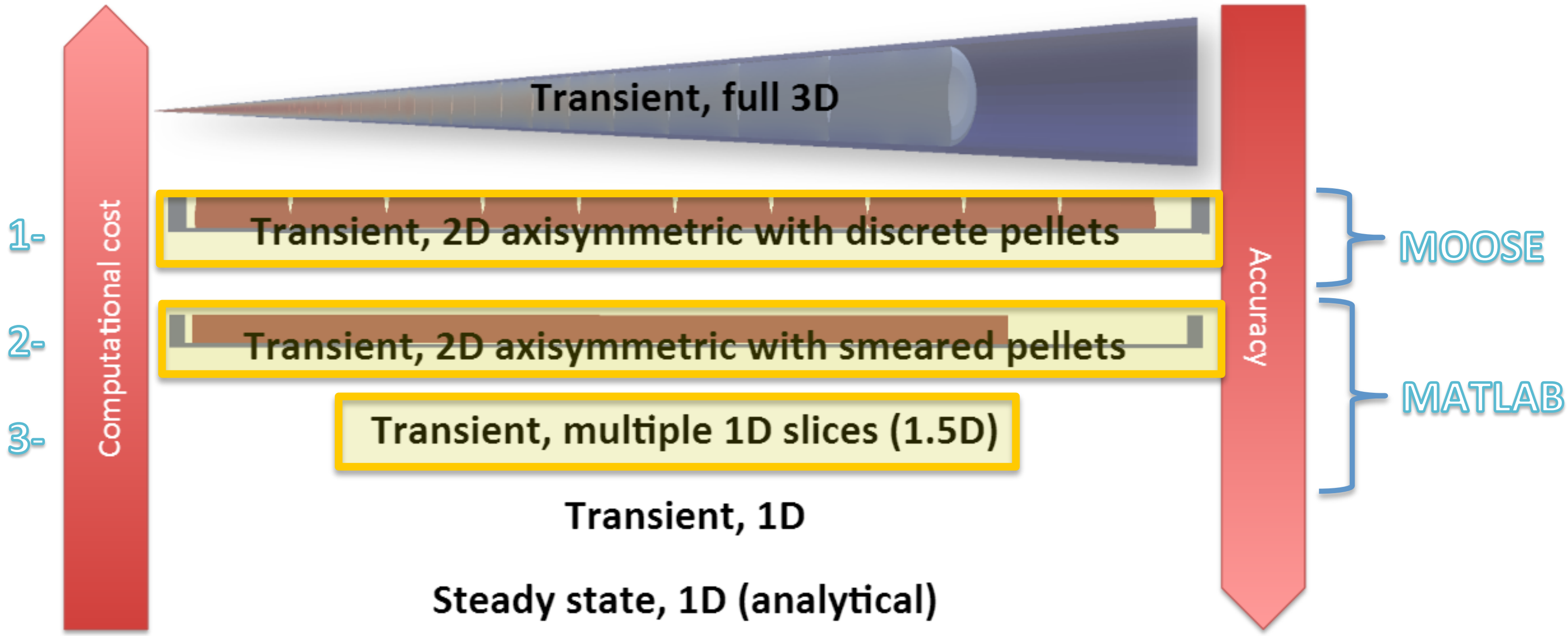
Project goal

The goal of this project is to create a simple fuel performance code and use it to investigate different cases.

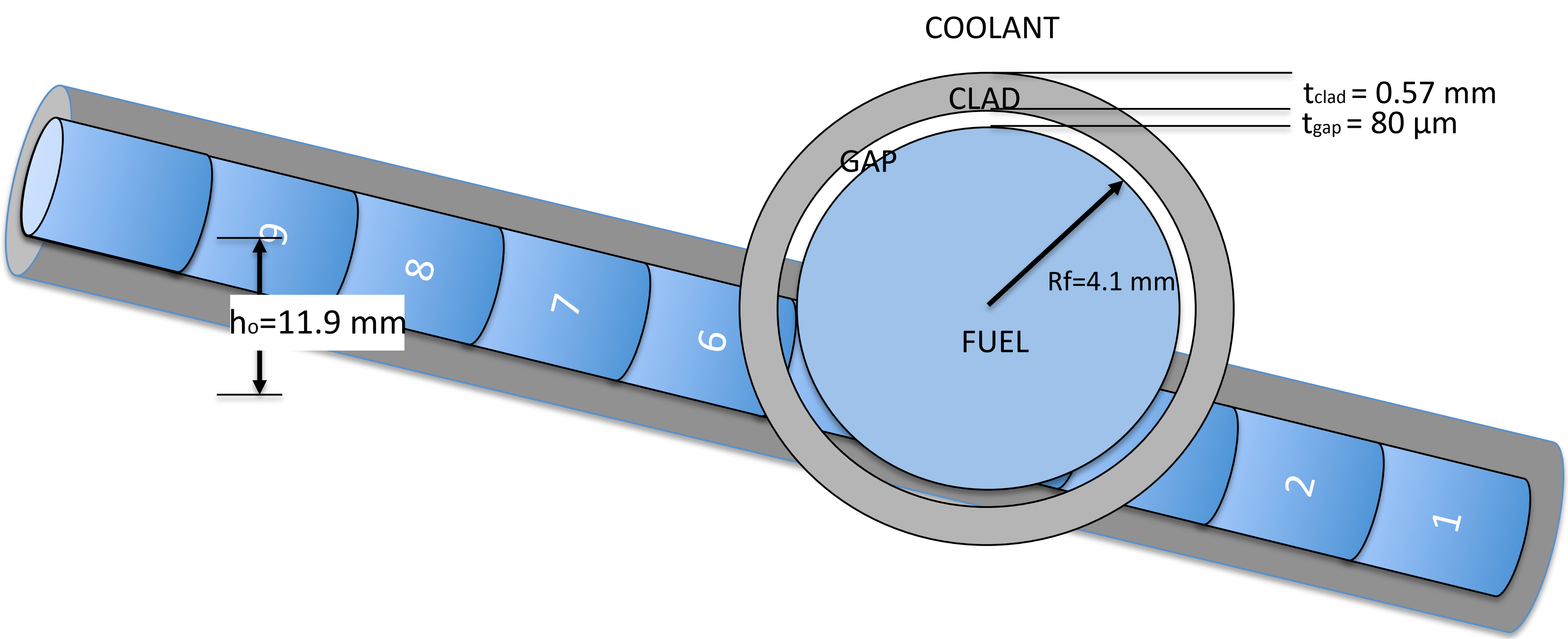


You will have the option to create a 1.5D code, a 2D RZ code with smeared pellets, or a 2D RZ code with discrete pellets.

General Description of the Project

You will model a fuel rodlet with ten UO2 pellets and surrounded by a zircaloy cladding:

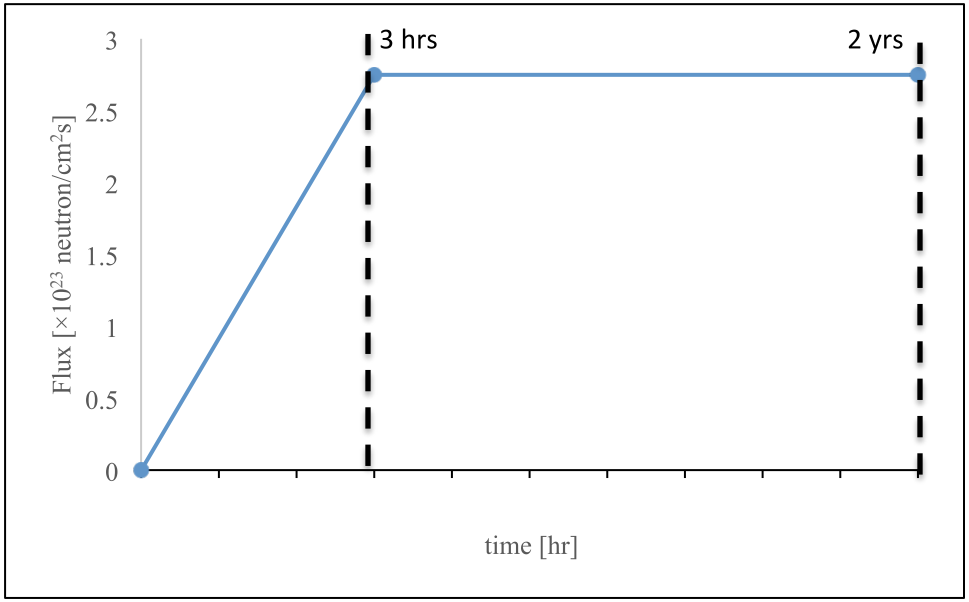
Pellet and Clad geometry:



General Description of the Project

Operating conditions:

- The power will linearly increase for 3 hrs before reaching its maximum value, resulting from a fission rate of 2.75×10^{13} neutron/cm^{2}s. Power will hold there for 2 years.



The linear heat rate will vary axially according to the equation:

$$LHR\left(\frac{z}{Z_o}\right) = LHR^o \cos\left[\frac{\pi}{2\gamma}\left(\frac{z}{Z_o}-1\right)\right] = LHR^o F\left(\frac{z}{Z_o}\right)$$

Where

- LHR^0 is the centerline linear heat rate (z = Z0)
- $\gamma = (Z_{ex}+Z_o)/Z_o$ where Z_{ex} is the extrapolation distance
- $\gamma \approx 1.3$

General Description of the Project

Operating conditions:

$T_{cool,in}$ = 580 K,

$\dot{m}$ = 0.25 kg/s

C_{pw}= 4200 J/kgK

The coolant temperature along the length of the rodlet using the equation from slide 18 of lecture 7:

$$\boxed{T_{cool} - T_{cool}^{in} = \frac{2\gamma}{\pi}\frac{Z_0 LHR^0}{\dot{m}C_{pw}}\left(\sin\left(\frac{\pi}{2\gamma}\right) + \sin\left(\frac{\pi}{2\gamma}\left(\frac{z}{Z_0} - 1\right)\right)\right)}$$

General Description of the Project

You will investigate three different cases:

Case A: Fuel, clad and gap properties are burnup independent

Case B: Fuel, clad and gap properties are burnup dependent

Case C: Simulation of loss of coolant accident

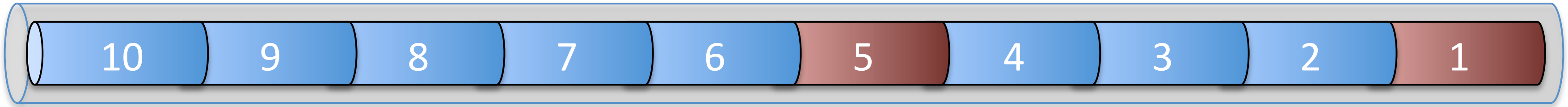
General Description of the Project

Case A: Fuel, clad and gap properties are **burnup independent**

Assumptions

- *Properties of the fuel, cladding and gap are independent of burnup,*
- *Thermal conductivity should change with temperature,*
- *You should consider the impact of thermal expansion on the gap size.*

Stop once your result reaches steady-state. Choose a reasonable constant time step size.



Output:

- **Plot T vs. radius for the bottom pellet and the 5th pellet from the bottom of the same plot.**
- **Compare against the analytical solution to make sure your solution makes sense.**
- **Turn in your data file!**

General Description of the Project

Case B: Fuel, clad and gap properties are burnup dependent

<u>Assumptions</u>

- *Properties of the fuel, cladding and gap are burnup dependent:*
  - *Swelling*
  - *Fission gas release*
  - *Burnup dependent thermal conductivity.*

Choose a time step size that gives your reasonable results without taking too long!

Instructions on how to incorporate these will be given in class as we learn about them!

<u>Output:</u>

Run your simulation for 2 years and

- **Plot To and Ts vs. time on the same plot for bottom pellet and the 5th pellet from the bottom pellet.**
- **Also indicate on your plot at what time these two pellets came in contact with the cladding.**
- **Turn your data files with these three quantities as a function of time.**

General Description of the Project

Case C: Simulation of LOCA

Simulate a loss of coolant accident with your code after 2 years of steady operation modeled in Part 2.

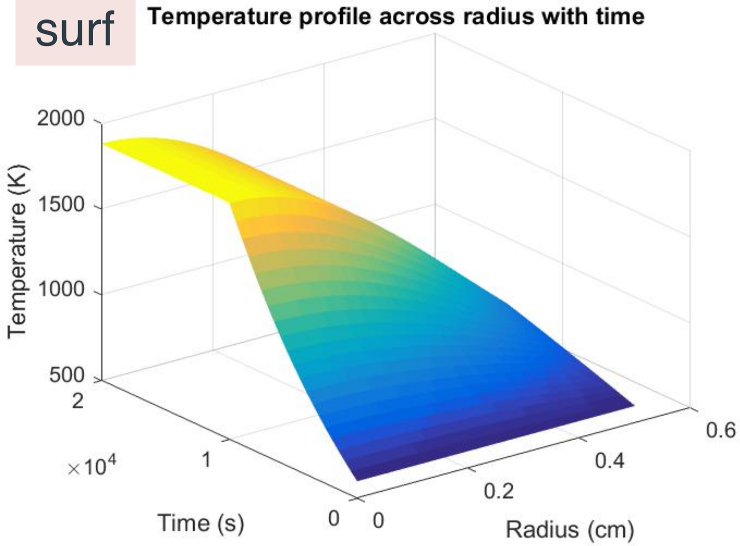
<u>Output</u>

- **If the coolant flow rate drops to 1×10^{-3} kg/s, will the fuel melt?**
- **How low must the coolant flow rate go for the fuel to melt after 6 hours?**
- **Turn in an image file showing the temperature profile throughout the fuel pellet when it reaches the melting temperature after six hours.**

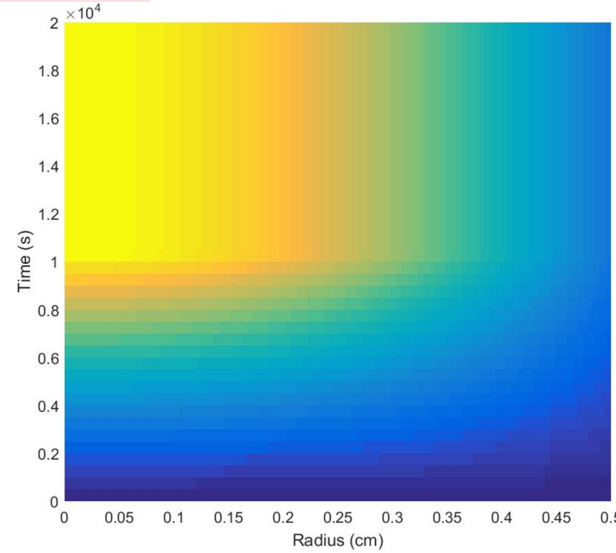
Specific Requirements for the approaches

1.5D in Matlab:

surf



View(2)



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- To plot the temperature profile across the … all the temperatures from all the axial slices. Plot it with the surf function and view(2) to make it a 2D shaded plot.

Specific Requirements for the approaches

2D in Matlab:

The details of your simulation are:

- Use a max element size of 1/10 the radius
- Use the iterative method from the homework to include the closing of the gap.
- Use the analytical method to determine the centerline temperature for the iterations.

Specific Requirements for the approaches

2D Discrete Pellets in MOOSE:

- Additional directions are provided with the files. Follow them. Do this as soon as possible to make sure you can get the code up and running.
- Three meshes are provided that are all interchangeable in the code.
- One is for smeared pellets, one for discrete pellets but a coarse mesh, and one for discrete pellets with a fine mesh.
- Your final results should use the discrete fine mesh, if possible. If not, you may be allowed to use the discrete coarse mesh (talk to Dr. Tonks).
- You will output your temperature profiles using VectorPostProcessors, as done in the example file. You will then need to plot the files in Matlab, Excel, or something similar.
- Make images of your solution using Paraview (makes the best images) or Peacock.

Deliverables

- Indicate your choice of creating a 1.5D, 2D smeared pellet, or 2D discrete pellet code

- A report presenting your results and summarizing your approach

- Several data files from your simulations (outlined above)

- One image file from your results for part 3 (more detail given above)

Requirements for the Final Report

Formatting requirements:

- No more than 4 pages
- 11 point font
- 1 inch margins on all sides
- To be turned in as a PDF file (you can use any program to write the report)

Section requirements:

- You must have the following sections:
  - Abstract
  - Introduction
  - Case 1
  - Case 2
  - Case 3
  - Conclusions
- You may have the following sections (they don't count towards the four pages):
  - References
  - Appendix