

## 22.39 HW#2

Fall 2006

Problem Statement

INTRODUCTION

In this exercise, you will be using VIPRE (a modern thermal hydraulics code) to understand and explain the thermal hydraulic capabilities of an oxide ( $\text{UO}_2$ ) and hydride ( $\text{U-ZrH}_{1.6}$ ) fueled BWR/5 reactor core. The core internals, reactor vessel and fuel canisters conform with the standard geometry of those found in a BWR/5. The oxide fuel bundles are nearly identical to the GE 9x9 design used in the current BWR/5 design, shown below in Figure PS2-1. The hydride fuel bundles are nearly identical to the oxide fuel bundles, except the water rods have been replaced with extra fuel pins, giving a uniform 9x9 hydride pin matrix.

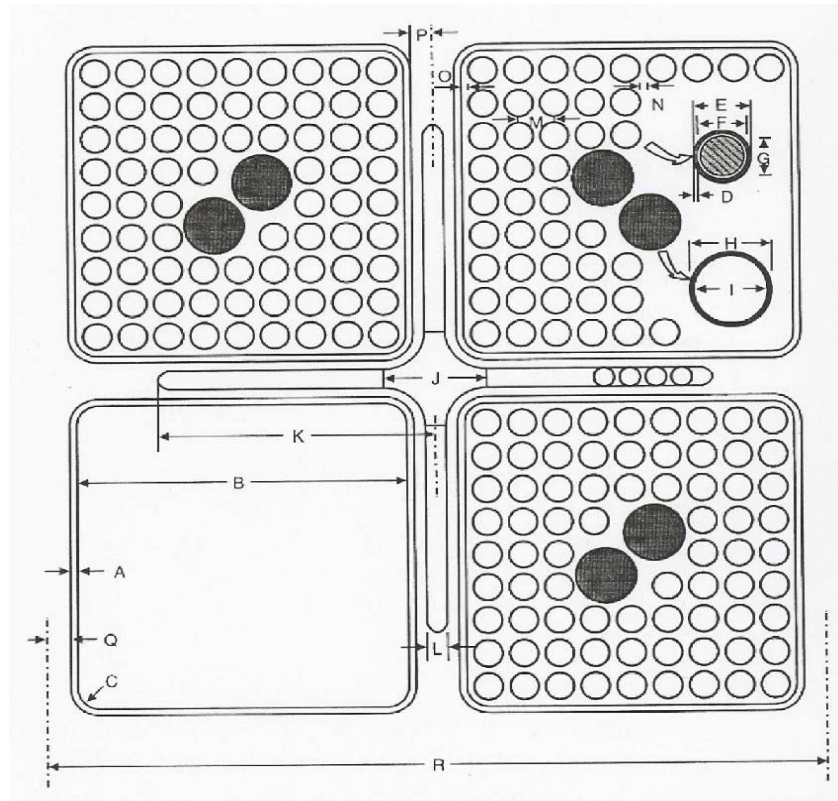


Figure PS2-1: Typical GE 9x9 BWR Fuel Bundle

Unless specified otherwise, all figures in this presentation are from:  
 Shuffler, C., J. Trant, N. Todreas, and A. Romano, "Application of Hydride  
 Fuels to Enhance Pressurized Water Reactor Performance." MIT-NFC-TR-077.  
 Cambridge, MA: MIT CANES, January 2006. Courtesy of MIT CANES.  
 Used with permission.

As well, the BWR/5 core modeling in VIPRE is shown below in Figure PS2-2. This is included as a reference to give you some feel for how a core may be modeled in VIPRE and to help you decipher the output file in answering Question #4.



Figure PS2-2: VIPRE Modeling of the BWR/5 Core and Internals

Some important core characteristics of the BWR/5 are:

Table PS2-1: BWR/5 Characteristics

Characteristic	Value
Number of Assemblies	764
Number of fuel pins per assembly	Hydride – 81 (9x9) Oxide – 74 (9x9 array geometry with 2 water rods)

You will be finding the maximum power achievable from both the hydride and the oxide fueled cores, subject to the given thermal hydraulic limits:

Table PS2-2: Thermal Hydraulic Limits

T/H parameter	Limiting Value	Where this value can be found in the output files
MCPR	1.015	End of outpt.txt
Core pressure drop	26.2 psi	Last line in pd.txt (values in this file are in units of psi)
Fuel centerline temperature	Oxide - 2805°C Hydride - 750°C	Rightmost column in fuelthr.txt (values in this file are in units of °F)
Average fuel temperature	Oxide – 1400°C Hydride – N/A	Second column from the right in fuelthr.txt (values in this file are in units of °F)

**IMPORTANT:** the values in fuelthr.txt are in °F and the limits above are in °C

As presented in the lecture, there are other thermal hydraulic limits of concern that would normally be used as constraints, e.g. flow velocity. However, in order to keep this problem set manageable, they have been omitted from this analysis.

### **MECHANICS OF RUNNING VIPRE**

The files that you will need accompany this problem statement in the .zip file that you downloaded from MIT server

- Hydride\_wholecore\_input.txt
- Oxide\_wholecore\_input.txt
- vipre.exe

Some important notes about VIPRE:

- VIPRE is a somewhat un-user-friendly program. A stray character in the input file will prevent the program from running properly, so be careful of what you change in the input file.
- VIPRE is FORTRAN application. Everything after a “\*” in the input file is a comment and is not used in the VIPRE calculations.
- The input file to execute VIPRE must be called “input.txt”
- In order to run VIPRE, place the executable and the input file in the same folder. Double click on the executable in order to run the program. If in a Windows environment, you should get a blank DOS screen that will be on your screen for <10 seconds (or so) and then will disappear once VIPRE is done calculating
- The output files will appear in the same folder. The main body of output will appear in a file called “outptt.txt.” All of the other files are text files with some specialized information.
- VIPRE will not run if there are already output files in the same folder as the input file and the executable. Therefore, in order to run subsequent cases, you must either delete or move ALL of the output files from that folder.

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## PROBLEM SET

As an aid to help with the successful completion of this Problem Set, the following paper has been included in the zip file with the rest of the necessary files:

P. Ferroni et al, "Feasibility of Improving BWR Performance Using Hydride Fuel," Proceedings of ICAPP '06, Reno, NV USA, June 4-8, 2006, Paper 6241.

1. (10 points) Keeping the power to flow (P/F) ratio the same, change the pin power (and the flow to correspond to the P/F ratio of 110.486 kW/lbm/sec) to find the maximum achievable core power, while still respecting the thermal hydraulic limits of Table PS2-2.
  - Change the name of the VIPRE input file called "Hydride\_wholecore\_input.txt" to "input.txt"
  - Find the line with "oper.5" in the comments at the end of the line
  - Adjust the power and flow as necessary to increase or decrease power while keeping the P/F ratio constant, respecting the thermal hydraulic limits listed in Table PS2-2. **IMPORTANT:** the power listed in oper.5 is the power of the average fuel rod (kW/rod) and the flow listed in oper.5 is the core flow (lbm/sec) for a 1/8<sup>th</sup> section (i.e. total core flow\*(1/8)). The P/F ratio above is the ratio of total core power to total core flow.
  - a. Record the core power, calculated from the pin power in oper.5 that gives you the maximum power while staying within the prescribed thermal hydraulic limits.
  - b. Repeat this process for the "Oxide\_wholecore\_input.txt" input file. Note that the 1/8<sup>th</sup> core flow to be entered as an input in oper.5 (for the oxide fueled case ONLY) must be equal to 96% of the 1/8<sup>th</sup> core flow obtained from the calculation of flow using the selected rod power and given P/F ratio. This is to account for the roughly 4% of flow that would normally go through the water rods, but is unable to be modeled explicitly in VIPRE.
  
2. (30 points @ 5 points for each part) Compare the results between the hydride and oxide fueled cores and answer the following questions:
  - a. Explain the thermal hydraulic differences between the hydride and oxide cores. For each case, which thermal hydraulic limits are approached? Justify why each of the limits should have or should not have been approached for both the hydride and oxide fueled cases.
  - b. Explain fundamentally why a higher power is achievable for the hydride fueled strategy.
  - c. Explain why the P/F ratio is kept constant in this exercise. (HINT: you may justify your answer using simple calculations, formulae, or hand-drawn plots, if you prefer.)
  - d. Discuss the reactor physics differences between the two fuel strategies. What neutronic limits would you expect to come up against?
  - e. Do the values for exit quality make sense? (HINT: search for the section called "channel exit summary" in the outpt.txt file) As designers, why should we be concerned with exit quality?

- f. What other engineering design concerns would you have with the proposed hydride fuel strategy? (HINT: Table PS2-3 may serve as a good starting point for answering this question)

Table PS2-3: Comparison of Hydride and Oxide Fuel Properties

Property	U(45%w/o)-ZrH <sub>1.6</sub>	UO <sub>2</sub>	Hyd/Ox
Density (kg/m <sup>3</sup> )	8256	10970	0.75
U density (kg/m <sup>3</sup> )	3715	9670	0.38
H/U ratio in the fuel	5	0	-
Melting T (°C)	After releasing H <sub>2</sub> , the remaining matrix (U+Zr) melts between 1135 and 1855 °C	2805	-
Th.conductivity (W/m K)	17.6 (~T independent)	2.8 (@ 1250°C)	6.3
Specific heat (J/kg K)	~331 (@ 550°C)	325 (@ 1250°C)	~1
Th.expansion (ΔL/L) (%)	~1 (@ 550°C)	1.3 (@ 1250°C)	~0.8
Swelling	Larger than UO <sub>2</sub>	-	-
Cold fuel-clad gap th.conductivity (W/m K)	35 (Liq. Metal)	0.238 (He)	147

3. (10 points – 3 measures of conservatism required for full credit) Discuss any conservatism or unused margin which may be resident in these calculations. Propose solutions for how to exploit this margin and discuss the pros/cons of each.
4. (10 points – 3 new ways VIPRE could be useful for full credit) Open the file “outpt.txt” and spend a few minutes looking at the output data in an effort to understand what kind of data can be obtained from VIPRE. List 3 ways in which VIPRE could be useful in examining thermal hydraulic limits other than those specifically addressed in this problem set.

Example answer (using a thermal hydraulic limit that IS addressed in this problem set):

- **Fuel temperatures** – VIPRE gives an output of fuel temperatures. This could be useful in assessing fuel performance phenomena associated with fuel temperatures.

Questions about this problem set can be directed to either the grader for this course, Chris Handwerk or Paolo Ferroni.