ENU 4134 – Reactor Thermal Hydraulics 2 (3 credits) Required Course – Fall 2009

1. Description: This course is the continuation of ENU 4133. Topics covered in this course include fundamentals of two-phase flow, governing equations of one-dimensional two-phase flow dynamics, two-phase friction multiplier, constitutive relationship and correlation void fraction, closure relationships for interfacial transport terms, fundamentals of heat transfer with phase change, pool boiling, forced convective boiling, condensation, correlation for two-phase heat transfer coefficient, thermal hydraulic design of fuel elements, subchannel thermal hydraulics, and thermal hydraulic design analysis methods for water cooled reactors.

2. Prerequisite: ENU 4133

3/4. Program Educational Objectives / Professional Components Supported by Course

1. Provide students with the ability to apply advanced mathematics, computational skills, science and engineering science, including atomic and nuclear physics, to identify, formulate, analyze, and solve nuclear and radiological engineering problems.

2. Provide students with knowledge of the fundamentals of radiation transport, interactions, and detection and with the principles required for the analysis, design, and safe operation of radiation producing devices and using equipment and systems.

4. Provide students with the skills needed to communicate effectively, work collaboratively, and understand their professional and ethical responsibilities and the impact of engineering solutions in a societal and economic context so they can pursue successful, productive careers in nuclear and radiological engineering.

5. Program Outcomes Supported by Course

Outcome a: an ability to apply knowledge of mathematics, science and engineering.

Outcome c: an ability to design a system, component or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability

Outcome e: an ability to identify, formulate and solve engineering problems.

Outcome k: an ability to use the techniques, skills and modern engineering tools necessary for engineering practice

Outcome l: an ability to apply advanced mathematics, science and engineering sciences, including atomic and nuclear physics, to nuclear and radiological systems and processes

Outcome n: an ability to work professionally in on or more of the areas of: nuclear power systems, nuclear instrumentation and measurement, radiation protection and shielding and radiation sources and applications

6. Instructor

DuWayne Schubring, Assistant Professor, Nuclear & Radiological Engineering
115B Annex (for now, likely will change during the term)
352-273-0306 (also likely to change)
dlschubring@ufl.edu
http://victr.nre.ufl.edu/Teaching/Fall2009/ENU4134.html
Office Hours: MW 1030-1200 and by appointment.

7. Teaching Assistant: None

8/9/10. Course Meetings: NSC 227, MWF 0935-1025 (UF "Period" 3). The final exam is scheduled for December 17, 1230-1430.

11. Material and Supply Fees: None

12. Text (Required): *Nuclear Systems I: Thermal Hydraulic Fundamentals*, N.E. Todreas and M.S. Kazimi, 1990 (1st edition). (ISBN: 1560320516)

While the course will touch on nearly every chapter in this book and some topics not covered in it, our efforts will focus on Chapters 5, 8, 11, 12, and 13. Some supplementary notes will be provided by the instructor throughout the course, either as hard copy during class or linked from the course website http://victr.nre.ufl.edu/Teaching/Fall2009/ENU4134.html

To complete some of the homework in this course, access to a scripting language such as MATLAB and a spreadsheet application will be required. The in-class presentation requires one of the following: (1) a portable computer with the student's choice of presentation software, (2) an OpenOffice presentation on CD, DVD, or USB-powered drive for use on the instructor's laptop, or (3) the appropriate data storage hardware and presentation format to interface with the classroom computer.

13. References

1. *Nuclear Heat Transport*, M. M. El-Wakil, 1978 (1st edition). (ISBN: 0894480146). A second book on nuclear-specific thermal issues.

2. *Transport Phenomena*, R. B. Bird, W. E. Stewart, E. N. Lightfoot, 2006 (2nd edition). (ISBN: 0470115394). A unified treatment of momentum and energy transfer (mass transfer, too) centered on balance equations. Nominally a chemical engineering textbook, but useful for most engineering applications. Nice tables of differential operators and various other material in cylindrical/spherical/cartesian coordinate systems.

3. Any undergraduate textbooks (typically aimed at mechanical engineering students) on thermodynamics, fluid dynamics, and heat transfer.

4. As the steam tables in T&K are not particularly comprehensive, especially in SI units, you'll want access to better ones. These could be found in previous textbooks or via software.

14. Course Outline

The material to be covered in each class is *approximate* – as we go along, we could move ahead of or behind this pace. However, the due dates (and exam dates) listed below *will not be adjusted*.

Exam Coverage:

1. Single-phase review, averaging, two-phase transport equations, HEM, SFM, two-fluid model, critical flow
2. Flow regime mapping, regime-specific phenomena, counter-current flow, pressure drop models, pool boiling, flow boiling, CHF
3. Comprehensive, but emphasis on single-channel analysis (conduction in rods, gap conductance, convection to coolant), nuclear power cycles, steam generators, and thermal design

Wk.	**Day**	**Date**	**Due**	**Material**	**Reading**
1	M	24 Aug		Course Introduction	
1	W	26 Aug		Introduction to Two-Phase Flow (1/2)	
1	F	28 Aug	HW 1	Introduction to Two-Phase Flow (2/2)	
2	M	31 Aug		Fluid Mechanics Review (1/2)	Ch. 4, 9
2	W	2 Sep		Fluid Mechanics Revew (2/2)	Ch. 4, 9
2	F	4 Sep		Heat Transfer Review	Ch. 10
3	M	7 Sep		NO CLASS MEETING (UF Holiday)	
3	W	9 Sep		Averaging in Two-Phase Flow	S 5-1, 5-2
3	F	11 Sep	HW 2	Volume/Area Averaged Parameters	S 5-3, 5-4
4	M	14 Sep		1-D Transport Equations (1/2)	S 5-5, 5-6
4	W	16 Sep		1-D Transport Equations (2/2)	S 5-6, 5-7
4	F	18 Sep	HW 3	Homogeneous Equilibrium Model	
5	M	21 Sep		Separated Flow Model	
5	W	23 Sep		Two-Fluid Model	
5	F	25 Sep	HW 4	Two-Fluid Model & Choked (Critical) Flow	S 11-6
6	M	28 Sep		Choked (Critical) Flow	S 11-6
6	W	30 Sep		Flow Regime Maps	S 11-2
6	M	2 Oct	HW 5	Vertical Bubbly Flow	
7	W	7 Oct		Vertical Annular Flow	
7	F	9 Oct		Vertical Intermittent Flow & Horizontal Flow	
7	?	?		Optional Review for Exam 1	
7	F	9 Oct	Ex. 1	Exam – in class	
8	M	12 Oct		Counter-current Two-Phase Flow	
8	W	14 Oct	Pr. 1	Pressure Drop Models (1/2)	S 11-5
8	F	16 Oct		NO CLASS MEETING (UF Holiday)	

Wk.	**Day**	**Date**	**Due**	**Material**	**Reading**
9	M	19 Oct		Pressure Drop Models (2/2)	S 11-5
9	W	21 Oct		Sub-cooled/Saturated/Nucleate Boiling	S 12-1–12-5
9	F	23 Oct	HW 6	Film Boiling & CHF	S 12-6, 12-7
10	M	26 Oct		Boiling & CHF Correlations (1/2)	
10	W	28 Oct		Boiling & CHF Correlations (2/2)	
10	F	30 Oct		Presentations of Project 2	
11	M	2 Nov		Presentations of Project 2	
11	W	4 Nov	Pr. 2	Conduction in Rods	
11	?	?		Optional Review for Exam 2	
11	F	6 Nov	Ex. 2	Exam – in class	
12	M	9 Nov		Gap Conductance	Ch. 8
12	W	11 Nov		NO CLASS MEETING (UF Holiday)	
12	F	13 Nov	HW 7	Convection to Coolant (1/2)	Ch. 13
13	M	16 Nov		NO CLASS MEETING (ANS)	
13	W	18 Nov		NO CLASS MEETING (ANS)	
13	F	20 Nov		Convection to Coolant (2/2)	Ch. 13
14	M	23 Nov		Rankine Cycles	S 6-5
14	W	25 Nov	HW 8	Brayton/Other Cycles	S 6-6, 6-7
14	F	27 Nov		NO CLASS MEETING (UF Holiday)	
15	M	30 Nov		Steam Generators	Ch. 2, 3
15	W	2 Dec		Steam Generators & Thermal Design Limits	Ch. 2, 3
15	F	4 Dec	HW 9	Thermal Design Limits	Ch. 2, 3
16	M	7 Dec		Metal-cooled Reactors	
16	W	9 Dec	Pr. 3	Gas-cooled Reactors	
17	?	?		Optional Review for Exam 3	
17	R	17 Dec	Ex. 3	Final Exam Period, 1230-1430	

15. Attendance and Expectations

In the event that a regularly scheduled class meeting is missed for a valid reason (other academic commitment, university athletics, personal/family emergency, religious holiday, etc.), please contact the instructor regarding what notes and other materials are available to assist in learning the material missed. Attendance will not directly affect the grade received for this course, but frequent absenteeism will affect knowledge of course material that will then affect the grade. If a student arrives late or needs to leave early, he/she is expected to do so with minimum disruption to other students. There is no tolerance for mobile phones or other electronic disruptions. **Such disruptions will lead to the student being told to leave the room for the duration of the class period, *including during examination periods* with the student's paper collected and no more work permitted.**

Homework will be collected as hard copy at the beginning of the class period at which it is due. Examinations must be submitted to the instructor as hard copy by the end of the class period. For some homework assignments, electronic submissions (a spreadsheet file, for example) may also be required. This will be indicated on the assignment sheet. Submissions *must* be in the form requested (spreadsheets exported to comma-delimited CSV files, MATLAB in its various native formats, etc.) If you do not know how to convert your files to this format, contact the instructor in advance of the deadline. Not knowing your software is not an excuse for late homework!

For the written reports of projects, hard copy by the end of the class session indicated is preferred, but electronic submission is accepted. Electronic submission *must* be in the form of a single PDF file, printable on letter (8.5" by 11") paper.

In addition to the required homework assignments noted above, recommended homework problems may be given throughout the semester. You will be responsible for the technical content of these homework problems (*i.e.*, they may contribute knowledge needed to perform well on projects or exams), but will not be included in the grade. Solutions to both required and recommended homework problems will be provided.

Homework will not be given any points if it is more than one week late or if it is turned in after solutions have been released (whichever comes *first*). Projects more than one week late will also have no value. Otherwise, late homework and project write-up assignments will have their grades computed as follows, where G_f is the grade received, G_s is the grade scored (grade if it were on time), and d is the number of days (including weekends, holidays, and other days class does not meet, rounded up) the assignment is late:

$$G_f = G_s d^{0.9} \tag{1}$$

Late assignment scores will be rounded to full points. No credit will be received for presentations not on time.

No collaboration is permitted during examination periods, although you may prepare for these however you choose. The allowable level of collaboration on homework assignments may vary throughout the course and is indicated clearly on each assignment. On projects, you will need to collaborate with and divide labor among the members of you team, but no collaboration between teams is permitted.

16. Grading

20% Homework (Best 8 of 9)
15% Exam 1
15% Exam 2
15% Exam 3 (final exam)
10% Project 1
15% Project 2 (10% for written report, 5% for in-class group presentation)
10% Project 3

There will a total of 1000 points available in the class. 1 exam point = 1 homework point = 1 project point

17. Grading Scale: Grades will be curved. The current distribution and estimated on-track-for letter grades will be provided to students several times during the course. UF has recently added minus grades (A-, B-, C-, D-) and adjusted the grade point equivalencies of plus grades (B+, C+, D+). See http://www.registrar.ufl.edu/catalog/policies/regulationgrades.html for the revised system.

18. Make-up Exam Policy: Will only be scheduled in extreme circumstances. Contact the instructor as soon as possible if necessary.

19. Honesty Policy: All students admitted to the University of Florida have signed a statement of academic honesty committing themselves to be honest in all academic work and understanding that failure to comply with this commitment will result in disciplinary action. This statement is a reminder to uphold your obligation as a UF student and to be honest in all work submitted and exams taken in this course and all others.

20. Accommodation for Students with Disabilities: Students requesting classroom accommodation must first register with the Dean of Students Office. That office will provide the student with documentation that he/she must provide to the course instructor when requesting accommodation.

21. UF Counseling Services: Resources are available on-campus for students having personal problems or lacking clear career and academic goals. The resources include:

- University Counseling Center, 301 Peabody Hall, 392-1575, Personal and Career Counseling.
- SHCC mental Health, Student Health Care Center, 392-1171, Personal and Counseling.
- Center for Sexual Assault/Abuse Recovery and Education (CARE), Student Health Care Center, 392-1161, sexual assault counseling.
- Career Resource Center, Reitz Union, 392-1601, career development assistance and counseling.

22. Software Use: All faculty, staff and student of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

Supplementary Discussion

In the prerequisite for this course, ENU 4133, you primarily studied single phase fluid mechanics. While that course is designed to serve students in the nuclear engineering curriculum, many of the concepts you learned apply well to other systems. Fluid mechanics is closely tied to thermodynamics and heat transfer – two other areas you have studied previously – and would suffice for a B.S.-level understanding of the thermal fluid sciences in many fields.

Nuclear engineers, however, do not have things quite that easy. This course, ENU 4134, will primarily focus on those topics specific to nuclear technology or unusually significant for it. Following a brief review of fluid mechanics and heat transfer phenomena, the next 8 weeks focus on two-phase flow. Most potential modes of thermal-induced failure in light water reactors are connected to phenomena in which both liquid and vapor phases are present. Our coverage begins with a theoretical treatment of the subject, right down to the two-phase transport equations for mass, momentum, and energy. This material is the source of the content of Exam 1.

While such theory is an accurate description of the system, it is often not helpful for engineering purposes. Instead, empirical models and correlations – ranging from those with hypothesized physics and only a couple empirical constants to pure polynomial fits – are predominant in analysis. In Project 1, you'll develop example correlations. The next few weeks are spent studying empirical models of two-phase flow. The distribution of the two phases in the system, termed the flow regime, is closely tied to which model to use. As a result, much of this block focuses on regime identification, mapping, and modeling. The discussion of two-phase flow concludes after this block with Exam and Project 2.

In the final 10-12 classes, we finally turn explicit attention back to a nuclear reactor. Knowledge of both single-phase and two-phase fluid mechanics and heat transfer is applied to the steady-state analysis of a single heated channel in an LWR, including analysis of the fuel elements themselves (Chapters 8 and 13). We'll also cover steam generators, which provides the material for Project 3, and thermal design principles. At the very end of the course, as time permits, we'll go into a brief discussion of non-LWR systems with an emphasis on thermal characteristics.

In addition to the program educational objectives outlined above, ENU 4134 will provide you the opportunity to tie together your previous thermal hydraulics courses and to understand how that material applies to nuclear fission systems. Your understanding of thermal hydraulics will include an unusually detailed knowledge of two-phase flow (relative to graduate of other majors, certainly, and also to other nuclear engineers at the B.S. level) and, hopefully, an appreciation of this area as one of continuing research. This makes you more marketable, whether you choose to seek employment with your undergraduate degree or go to graduate school in thermal hydraulics or other areas. (If you're interested in pursuing graduate school, particularly in TH and whether here at UF or elsewhere, your instructor is an excellent resource.) Along the way, you'll be expected to develop communication skills, team skills, and engineering judgement pertaining to the course content.

Your performance will be evaluated in three primary ways:

- Exams – Three exams have been scheduled, linked to the three areas of the course (two-phase theoretical, two-phase empirical, and nuclear-specific analysis).

- Projects – Three projects have scheduled during the term, for completion in (mostly) groups of 3. These allow you to closely simulate actual engineering tasks. Each concludes with a write-up and supporting calculations. These naturally incorporate teamwork and communication skills (written for all three, verbal for Project 2) into your engineering studies. Here in the academy, your technical writing experience is primarily cordoned off in specific courses. In the real world, you'll need to communicate just about all the work you do.

- Homework – The homeworks, which generally are due in weeks without projects or exams, are intended to be completed in a few hours each. Their primary purposes are to keep you working on the course material, at least a little each week, and to let you and your instructor know if you are grasping course concepts. While they will be graded, your final standing in the class will be predominantly determined by your performance on exams and projects as homework grades tend to cluster high.

A number of UF-recognized holidays interfere with the schedule for this course, as does the ANS Winter Meeting. Most due dates are set for Fridays. In exchange for the two class hours missed as a result of the ANS meeting, your instructor will provide three one-hour review sessions throughout the course, one for each of the exams. Attendance at these will be optional; they will be scheduled as the course goes along to maximize the number of students who attend.

There is a lot of material to cover in this course with one topic often building on the previous. Please contact your instructor in class, over e-mail, or in office hours if you start to slip on the material – don't let a little difficulty turn into a big problem. For the moment, the nuclear engineering major remains a small one. Take advantage of this during class – ask questions and contribute to the discussions.