Abstracts of NE Course Offerings: R. R. Schultz

The courses listed below are available, as needed, for students at Idaho State University via the Nuclear Engineering Dept. in either an in-class (IC)[1] or a directed-study (DS)[2] format. These courses have been taught by Dr. R. R. Schultz, as needed, at either Idaho State University[3] or Texas A&M University[4] since 2010.

Students interested in the course offerings listed below should contact either Dr. R. Schultz or Dr. Chad Pope (Head of Dept of Nuclear Engineering) as appropriate.

1. Advanced Fluid Mechanics—DS format

Text: R. L. Panton, *Incompressible Flow*, 2013, John Wiley & Sons, 4th Edition

Abstract: Advanced fluid mechanics, which focuses on incompressible flow, is a necessary ingredient in the basic understanding of computational fluid mechanics and other tools necessary to analyze not only fluid mechanics problems but also fluid mechanics in the presence of heat transfer. One of the necessary ingredients in the understanding of advanced fluid mechanics is a good working knowledge of vector and tensor calculus. Therefore the course progresses as follows: a review of continuum mechanics and thermodynamics followed by a brief review of vectors and tensors and applications to kinematics. Thereafter the course covers the Navier-Stokes equations, dimensional analysis and exact solutions to the Navier-Stokes equations, ideal flows, vorticity dynamics, high Reynolds number flows and boundary layer flow, and finally turbulent flow.

2. Advanced Thermodynamics—DS format

Text: Y. A. Cengel and M. A. Boles, 2015, *Thermodynamics—An Engineering Approach*, McGraw-Hill

Abstract: A graduate-level thermodynamics course intended to introduce students to advanced concepts and applications. Thermodynamic property relationships, gas mixtures, thermodynamic optimization, irreversible thermodynamics, constructal theory, applications towards solar power, power generation, and refrigeration systems.

---

[1] In-class: Topic is addressed in recorded lectures in a class-room setting.
[2] Directed-study: Topic is addressed by periodically meeting with student to answer questions and monitor progress.
[3] Research Professor, Dept of Nuclear Engineering at ISU since 2014. Schultz was Adjunct Associate Professor at ISU from 2010 to 2014.
[4] Professor of Practice, Dept of Nuclear Engineering at Texas A&M University from 2012 to 2019.

3. Computational Fluid Dynamics-IC or DS formats

Text: J. C. Tannehill, D. A. Anderson, and R. H. Pletcher, *Computational Fluid Mechanics and Heat Transfer*, 2nd, 3rd, or 4th edition.

Abstract: The use of computational fluid dynamics and heat transfer is widely used these days in every field of engineering. Interestingly enough, CFD has been used only recently in the nuclear engineering field, in particular for licensing purposes, because of the (i) the predominance of two-phase, transient problems which even today are often too complex to be analyzed using CFD and (ii) the enormous range of interest for many plant scenarios[5]. Instead systems analysis software is generally used for analysis. Currently CFD is generally not used for performing licensing calculations for LWRs but is instead used for performing design performance calculations for operational conditions, for example a study of symmetrical inlet velocity and temperature conditions at the core inlet.

This class will focus on:

- **The discretization techniques used to develop CFD software.**
- **Sources of errors and calculational uncertainties.**
- **Common verification and validation techniques.**
- **Becoming familiar with widely used multi-physics, commercially-available software: COMSOL, FLUENT, or STAR-CCM+ which are often used for performing CFD calculations. The CFD code used may be dependent on accessibility, e.g., national laboratory resources vs ISU resources.**
- **The kinds of problems which are commonly studied in the nuclear field. It should be noted that the advanced reactors, because their working fluids are generally single-phase for not only operational conditions, but also accident scenarios, are ideal environments for analyzing the behavior of these systems for the key scenarios and figures-of-merit.**

4. Fluid Transients—DS format

Text: Frederick J. Moody, 1990, *Introduction to Unsteady Thermofluid Mechanics*, John Wiley & Sons.

Abstract: Most engineering problems are inherently time-dependent, although slow rates of change for primary variables may allow the system to be analyzed as a quasi-steady-state problem. Other considerations include the interplay of multi-physics where the rapid rate of change of one phenomenon compared to rates-of-changes in other system phenomena may dictate the analysis requirements for the problem under consideration. For example, the presence of pressure pulses moving at sonic velocity through a system. This course focuses on unsteady thermodynamics, convective propagation, hydrostatic waves (small- and large-amplitude), unsteady thermofluid systems and how to normalize them, one-dimensional bulk and water-

---

[5] A typical leak scenario in a nuclear reactor (light water reactor) has an initial condition of 15 MPA with 30 degrees subcooling and a final condition of 2 or 3 bars at saturation conditions.

hammer flows, one-dimensional large-amplitude pressure waves, multidimensional incompressible bulk and water hammer flows, and miscellaneous topics.

5. Gas Dynamics—DS format

Text: Robert D. Zucker & Oscar Biblarz, 2002, *Fundamentals of Gas Dynamics*, 2nd Edition, John Wiley & Sons.

Abstract: Fundamentals and practical applications of compressible fluid flow and gas dynamics; techniques for isentropic, friction, heat addition, isothermal flow, shock wave analysis, propagation, expansion waves, reflection waves.

6. Nuclear Reactor Safety & Economics—IC or DS formats

Text: Ronald Allen Knief, 2014, *Nuclear Engineering—Theory and Technology of Commercial Nuclear Power*, 2nd Edition, American Nuclear Society.

Abstract: The factors which both define (govern) and otherwise influence nuclear reactor safety and economics are studied. The course is divided into 5 broad areas with individual subjects identified as listed below:

I. Reactor safety and economics: their roles in commercial nuclear power
A. Economics—an introduction
1. Major factors: capital costs, operational considerations, and characteristics
2. Nuclear power plant design generations
3. Nuclear power: a versatile source of power
4. France and the US: 2 leaders and 2 approaches
B. Safety—an introduction
1. Evolution of commercial nuclear power
2. Pivotal events
II. Reactor safety fundamentals
A. History of nuclear regulation
B. Defense-in-depth: prevention, protection, and mitigation of accidents
C. Five sources of energy available in reactor accidents
D. Classification and description of accidents
E. Fission product releases: rates of release to containment and environment; residuals
III. Reactor safety systems and accident risk
A. Engineered safety systems
B. Role of LOFT and other experimental programs in reactor safety
C. Role of event tree and fault-tree methodologies as applied to risk assessment.
D. Justification of 10^{-9} per reactor-year estimate of most serious WR accident
E. Relative roles of WASH-1400, IDCOR, NUREG-1150 in assessment of LWR risk

F. **Key issues: direct containment heating, filtered vented containment, ex-vessel core retention, station blackout, and interfacing-system loss-of-coolant accident (LOCA)**

IV. **Reactor operating events, accidents, and their lessons**
   A. **Role of operating events in improving nuclear reactor safety**
   B. **Precursor events and accident sequences: LOCA, undercooling, overcooling, loss-of-electrical power, reactivity initiated and external events.**
   C. **Study of Three Mile Island, Chernobyl, and Fukushima events**

V. **Regulation and administrative guidelines**
   A. **Review of effects of Atomic Energy Act of 1954, Energy Reorganization Act of 1974, Department of Energy Reorganization Act of 1977 on federal regulation of nuclear energy**
   B. **The Code of Federal Regulations: importance, role, and key ingredients**
   C. **Federal agencies that play a role in governing nuclear power (commercial)**
   D. **The USNRC licensing process**
   E. **Differences between the US and some other regulatory agencies overseas**

Included in the topics outlined above is an introduction to the Final Safety Analysis Report (FSAR) which is written and maintained for every nuclear plant in the United States and in most nations which have commercial nuclear power. In-depth discussions of the "defining" transients such as the large break loss-of-coolant accident (LOCA), the small break LOCA, and selected severe accidents are given. The evolution from a deterministic analysis approach to a combination deterministic-probabilistic analysis approach is described. An important fraction of the course will be devoted to y a clear understanding of how the nuclear industry developed and validated the numeric analysis tools required to analyze the very complex transients that define each plant design's operational/accident envelopes. Subsequently a summary of the evolution of nuclear safety analysis thermal-hydraulic tools from systems analysis to computational fluid dynamics-based tools will be touched on. Discussions on the present "nuclear safety construct" and a proposed "new nuclear safety construct" will be held. Finally, a summary of typical system analysis techniques used to analyze a plant state will be given.

7. **Thermal-Hydraulics—IC or DS formats**

Text: Neil E. Todreas and Mujid S. Kazimi, 2012, *Nuclear Systems Volume I: Thermal Hydraulic Fundamentals*, 2nd Edition, Taylor & Francis.

Abstract: Thermal-hydraulics is a key ingredient in understanding and analyzing the behavior of nuclear systems. The commercial nuclear power industry relies heavily on light water reactors (LWRs) where water is the working fluid in the primary and the secondary as well as the medium used to cool the reactor core. Many of the problems which require analysis have only single-phase flow and heat transfer, i.e., single-phase thermal-hydraulics (TH). However, two-phase TH is also important under (a) normal operational conditions as water is boiled in the steam generators (boilers) to produce steam to spin the turbines and produce electrical power via the Rankine cycle

and (b) abnormal transient conditions as both boiling and condensation occurs during anticipated operational occurrences, design basis accidents, and beyond design basis accidents. Of special importance are the loss-of-coolant accident scenarios.

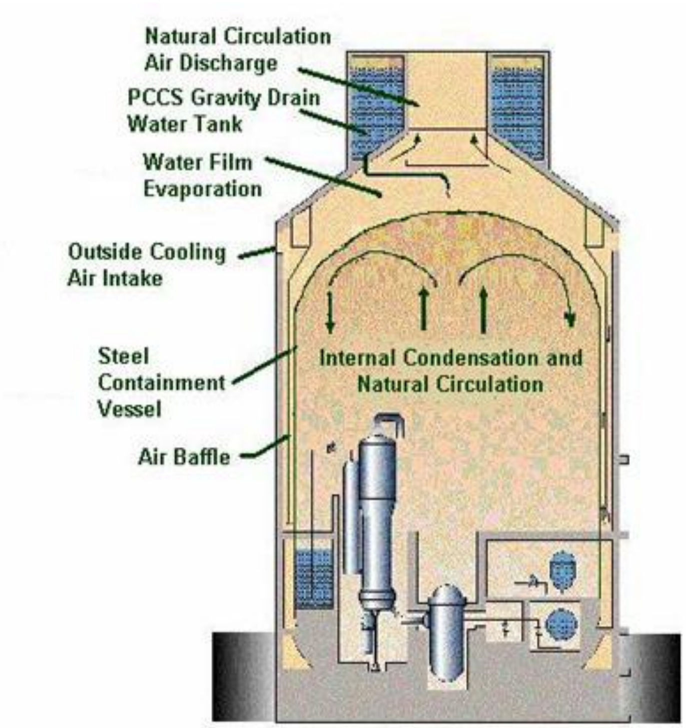
Both single-phase and two-phase TH are also quite important in understanding and analyzing the behavior of advanced reactors such as gas-cooled reactors, liquid metal-cooled reactors, and passive LWRs. To generate power both the Rankine and the Brayton cycles are used. Even the advanced reactors which normally have only a single-phase working fluid, even under most accident conditions, have accident scenarios where two-phase flow is present, e.g., water ingress in gas-cooled reactor systems.

Single-phase and two-phase TH will be studied in the context of typical nuclear system equipment components and geometries. Relevant physics will be presented and illustrative problems will be analyzed using first principles, and for a few special cases by using a systems analysis code to provide a basis for comparison with counterpart hand calculations.

8. Transport Phenomena: Theory & Applications—IC or DS formats

Text: R. Byron Bird, Warren E. Stewart, and Edwin N. Lightfoot, *Transport Phenomena*, 2007, John Wiley & Sons, Revised 2nd Edition.

Abstract: The study of transport phenomena is the unified study of mass, momentum, and energy transfer. This course is aimed at the study of mass, momentum and energy transfer theory and applications of the theory from a unified perspective. To achieve this goal the 2nd Edition of the famous text: *Transport Phenomena* by R. B. Bird, W. E. Stewart, and E. N. Lightfoot will be used together with examples from the commercial power and process heat industries—in particular from online Rankine and Brayton cycle power plants as well as the steam supply community.



Good examples of mass, momentum, and energy transport acting in concert in the commercial power community are provided by the transport phenomena present during steam discharge from a valve into the air environment within the Westinghouse AP1000 plant passive containment shown at right. The steam discharge forms a plume that moves upward. A partial list of phenomena includes:

Momentum interchange occurs between the steam plume and surrounding air. Steam condensation occurs on the internal surface of the containment structure walls as energy (heat) is transferred to the containment wall. As a result a downward flowing film of the steam condensate is formed on the interior wall surface of the containment. Concurrently on the exterior surface of the containment wall the water film created by water draining under the influence of gravity from the passive containment cooling system (PCCS) water tank and deposited on the upper elevations of the exterior containment wall is evaporated to the outside environment. Environmental air flowing through the outside cooling air intake is directed to flow from the bottom to the top of the exterior containment wall adjacent to the downward flowing evaporating film via density gradients. Concurrently, the density gradients within the containment created by the presence of the hot structures and the steam plume result in natural circulation of the gases within the containment.

The mathematics of transport phenomena, such as those described above, are explored and the physical significance of the phenomena and their interrelationships are studied using real systems as examples. The homework will consist of problems from the text plus supplemental problems.

9. Two-Phase Flow & Heat Transfer—IC or DS formats

Text: John G. Collier and John R. Thome, 1994, *Convective Boiling and Condensation*, 3rd Edition, Oxford University Press.

Abstract: Two-phase flow is omnipresent in the commercial nuclear power industry—which relies primarily on light water reactors which use water as the working fluid in both the primary and the secondary. However, two-phase flow is also important in dealing with advanced reactors, e.g., gas-cooled reactors, liquid metal reactors, etc since these reactors either use the Rankine cycle with steam generators (water as the secondary working fluid) or have scenarios where water ingress is important (note: water ingress into a gas-cooled reactor is two-phase multi-component flow). Thus, two-phase flow is encountered during steady-state operation (in the steam generators and in some designs in the reactor primary) and also, in various forms, during a multitude of transient scenarios[6]. The various two-phase flow regimes will be studied including pool and convective boiling, subcooled boiling heat transfer, saturated boiling heat transfer, critical heat flux, and condensation. Discussions will be held on the evaluation of void fraction and pressure drops in these flow regimes. In addition, special topics[7] on important phenomena relevant to single- and two-phase flow will be described including fully-developed flow, the flow behavior at inlets (contractions), exits (expansions), critical flow, and two-component hydrodynamics, e.g., air-water.

---

[6] Two-phase flow is not limited to liquid-gas components. Two-phase flow also occurs when solid particles are transported in liquid or gas. However, the course will focus predominantly on liquid-gas, one-component flow (liquid water and steam).
[7] Material for special topic discussions will be drawn from the references.

10. Verification & Validation—IC or DS formats

Text: William L. Oberkampf and Christopher J. Roy, *Verification and Validation in Scientific Computing*, 1st Edition, Cambridge University Press, 2010.

Abstract: This course addresses the application of verification and validation (V&V) techniques developed in engineering communities such as aerospace, automotive, and Department of Defense (DOD) communities using advanced, high-fidelity computational tools based on first-principles (e.g., computational fluid dynamics and heat transfer)—to computational tools used in the nuclear community.

Whereas the techniques developed to V&V advanced, high-fidelity computational tools are sophisticated and comprehensive, the traditional techniques used in the nuclear community are different by nature stemming from the types of numerical analysis tools required by the scenarios that require analysis in the nuclear community. The nuclear community developed "systems analysis" computational tools such as RELAP5, CATHARE, RETRAN, TRACE and others capable of analyzing the behavior of not only the nuclear reactor as the source of power directed to producing commercial electrical power via Rankine cycles, but also the behavior of such systems undergoing design basis events including such scenarios as the large break loss-of-coolant accident (LBLOCA) where a typical pressurized water reactor (PWR) system may depressurize from pressures in excess of 15 MPa subcooled conditions to 0.4 MPa saturated conditions in only a few minutes. The systems analysis computational tools developed to analyze such events used ill-posed partial differential equations (PDE) and first-order discretizations of these equations together with scores of correlations imposed on the framework of the conservation-equations since the first-principle physics are generally not known even to this day.

However with the recent interest in designing and building advanced nuclear systems, the advanced high-fidelity computational tools developed in other engineering communities are fast becoming the computational tools of choice. And together with this development goes the application of advanced V&V techniques.

The course will explore the following topics in detail:

1. **The differences and similarities of the V&V techniques used historically in the nuclear community—generally identified as "assessment studies"—with the advanced V&V techniques developed and applied to advanced high-fidelity computational tools.**
2. **The use of advanced V&V techniques on high-fidelity software.**
3. **The ingredients that make up historical V&V techniques and which are still applied to vintage computational tools—since advanced techniques are not generally applicable to vintage analysis tools.**