NUCLEAR REACTOR KINETICS

Lecture 1

Course Overview/Introduction

Massachusetts
Institute of
Technology

22.S904 Professor: Kord Smith

- Office: 24-221
- Phone: 252-1570
- Email: kord@mit.edu

- Office Hours: MWF 8:30-9:30 or by appointment (I am very flexible)

- "Grader" ???????

- Course Texts: None Required

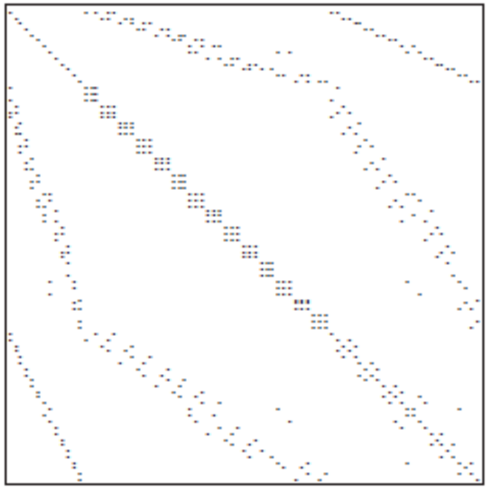
Paul Reuss,	*Neutron Physics*: general reactor physics
Weston Stacey,	*Nuclear Reactor Physics: volume of historical methods: online*
Gilbert Strang,	*Computational Science and Engineering*
Yousef Saad,	*Numerical Methods for Large Eigenvalue Problems: online*
Yousef Saad,	*Iterative Methods for Sparse Linear Systems : online*

Use any thing you find useful, and share with the rest of us!

- Course Grading:

7 Problem sets/programming exercises	(35%)
1 Midterm Exam	(25%)
Project	(40%)
Final Exam	None

22.S904 Useful Background Texts on Numerical Methods



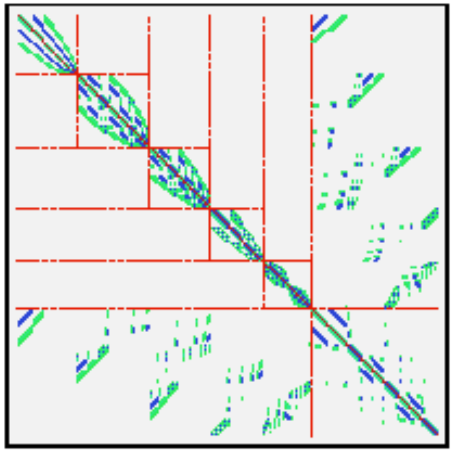
NUMERICAL METHODS FOR LARGE EIGENVALUE PROBLEMS

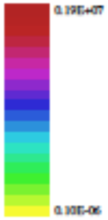
Second edition

Yousef Saad

Iterative Methods for Sparse Linear Systems

Second Edition





Yousef Saad

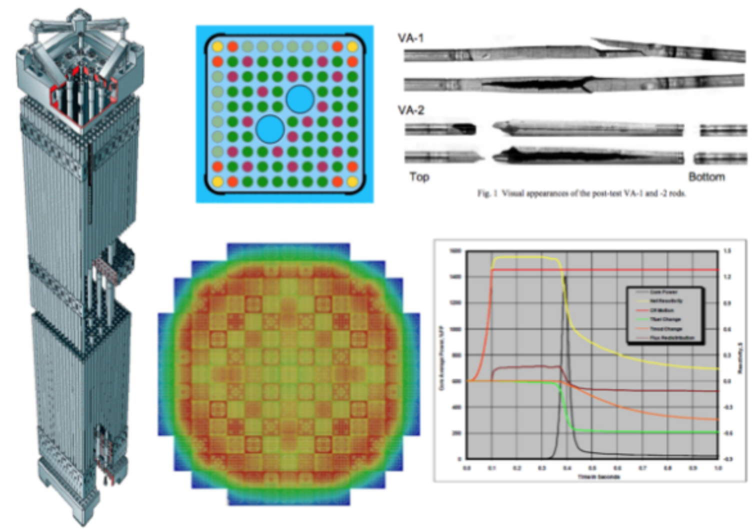
Stellar web site for 22.S904

- Syllabus: Lecture by Lecture under development/dynamic
- Background reading materials
- Lectures notes/slides ("hand-to-mouth")
- Assignment posting
- Assignment submissions
- Grades posted online

22.S904 Nuclear Reactor Kinetics (e.g. Dynamics)

Fall 2012

edit homepage



Instructor: Kord Smith edit personal info add/remove

Lecture: MW1-2.30 (24-115)

Information:

NSE's reactor physics sequence is being upgraded with new courses to provide students with stronger fundamentals and enhanced analysis, modeling and computational skills needed

22.05/22.211

Nuclear Reactor Physics 1, for students without reactor physics backgrounds. (the two classes are co-taught for senior undergraduate and first-year graduate students, **annual**)

22.212

Nuclear Reactor Physics 2, for students with reactor physics backgrounds. (e.g., undergraduate or graduate reactor physics in nuclear engineering, **annual**)

22.213

Monte Carlo Neutronics and Reactor Kinetics, for advanced graduate students. (pre-requisite 22.211, **bi-annual**)

22.251

Systems Analysis of The Nuclear Fuel Cycles, for any student interested in studying fuel cycles. (pre-requisite 22.05 or 22.211, **bi-annual**)

Reactor Physics Curriculum Revamping

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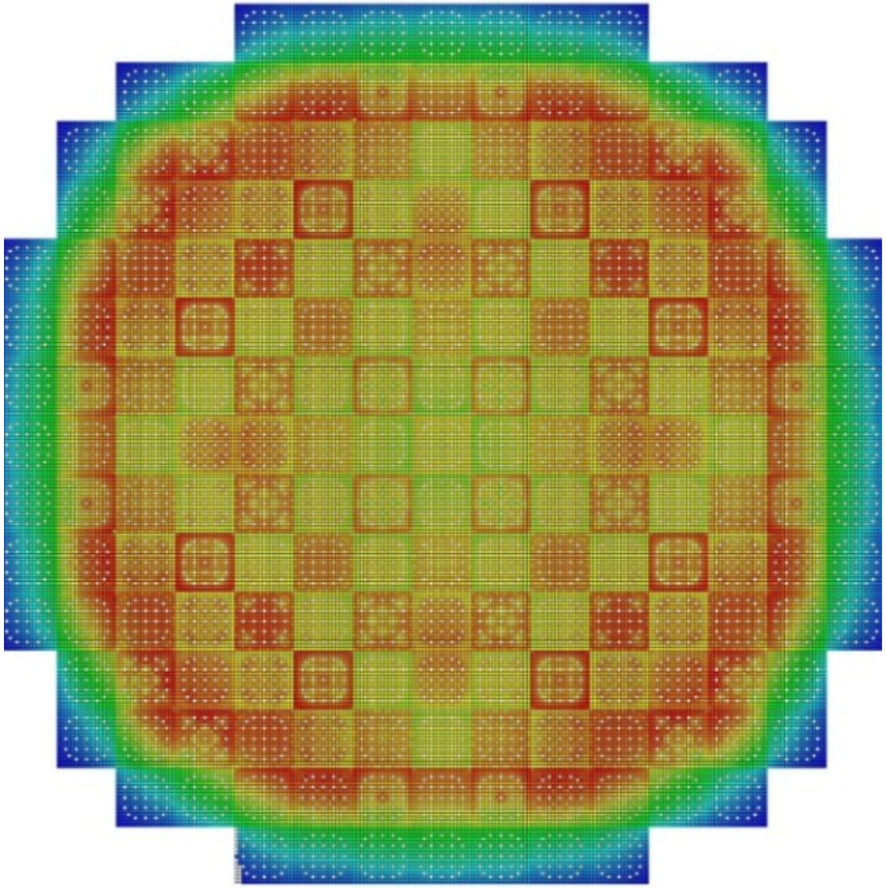
The 22.211 taught by Prof. Smith in Spring 2012 was taught at a very high level, partly as a transition course for the new structure. The more fundamental portions of that material will now be taught in the new 22.211 (introduced in the Fall 2012) and advanced material will be moved to 22.212 (Spring 2013), along with numerous more challenging topics.

22.213 (to be introduced in the Fall 2014) will cover both Monte Carlo neutronics and nuclear reactor kinetics at an advanced level. The Monte Carlo neutronics will incorporate basic concepts students have seen in 22.106, along with more advanced topics needed to fully understand the solution of reactor core eigenvalue problems. MIT's OpenMC reactor core analysis Monte Carlo tool will be heavily used for class applications.

22.S904 will build on the student's background in reactor physics to develop a deep understanding of concepts in time-dependent nuclear reactor core physics, including coupled non-linear feedback effects. Students will be exposed to computational numerical algorithms needed to solve real-world reactor physics problems, and students should be prepared to do significant computer programing in homework and semester projects. Topics include time-integration methods, automatic time-step control, quasi-static approximations, finite-difference and finite-element approximations, iterative solution methods (e.g., CG, GMRES, JFNK, MG, nonlinear acceleration, PETSc solver applications).

LWR Analysis for General Safety Analysis/Licensing



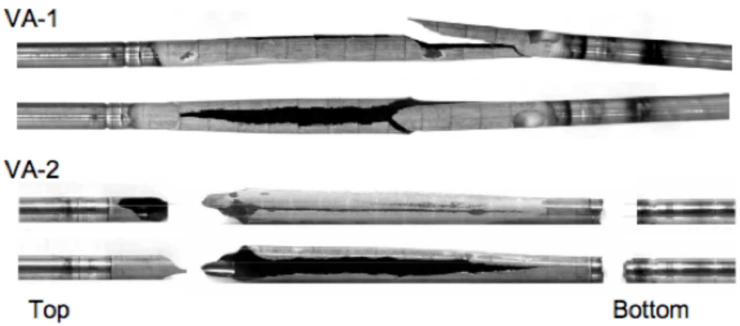
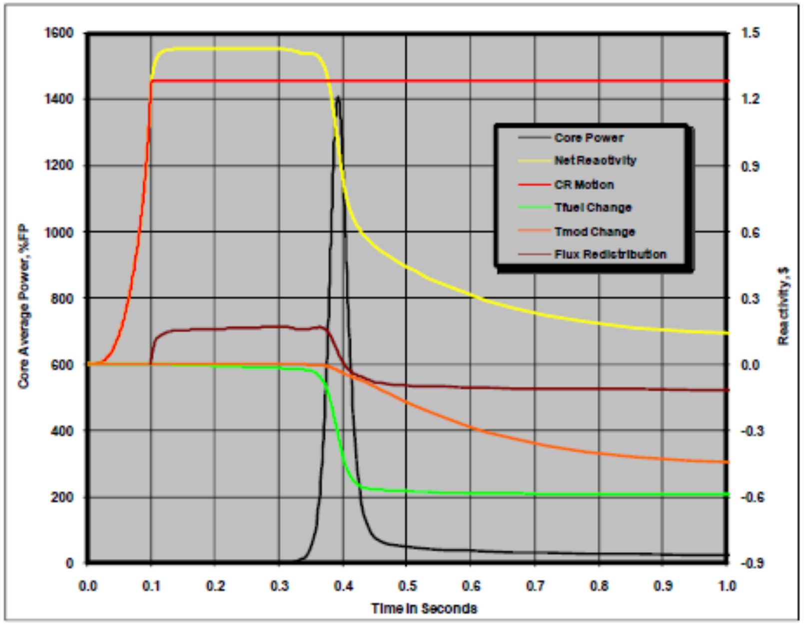


Fig. 1 Visual appearances of the post-test VA-1 and -2 rods.



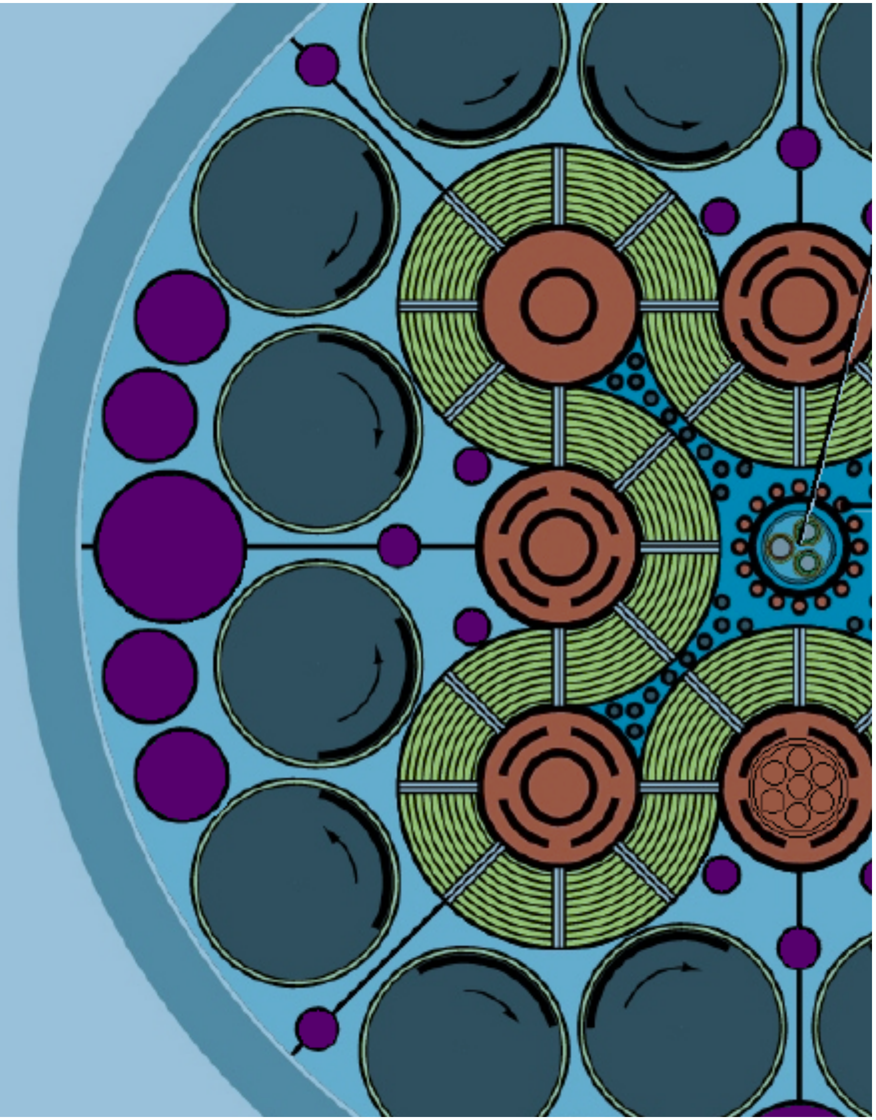
Course Philosophy

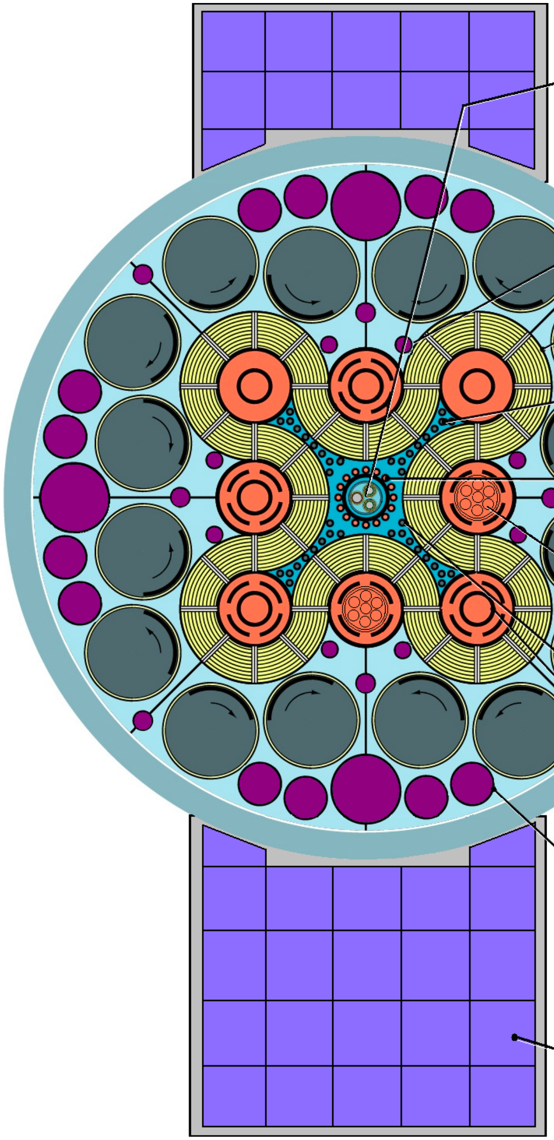
- This course has numerous major goals for your takeaways:
  - To understand classic physics approximations used to solve transient reactor analysis e.g., PKE, quasi-statics, synthesis, first-order temporal (and spatial) finite-differences
  - To understand higher-order temporal approximations for coupled linear equations
  - To understand some of the basic concepts of numerical methods (linear matrix algebra) that underlie iterative solutions of transient neutronics equations
  - To understand transient advanced nodal diffusion methods as used in production today
  - To understand the importance and impact of non-linear feedbacks in reactor behavior
- Programming problems sets are a necessity to truly understand course material
- Problem sets will require use of MATLAB, Python (or higher level programming languages, such as C, C++, or Fortran).

Ulterior Motives: This is not a Passive Class!

- There are also a number of self-serving goals for my takeaways:
  - To jump start some students directly involved in important on-going research projects
  - To document the computational efficiency of currently-touted "advanced" methods
  - To explore numerous methods used to accelerate solution of transient equations, many of which I have never actually used.
  - To explore and understand the efficiency of various parallel implementations of solvers
  - For you to take a major role in developing material for 22.213 (for 2014 class)
  - For you to explore some uncharted territory in transient algorithms and implementations
  - For you to help develop techniques that help lead the world in computational efficiency
- Semester Projects will be used to develop in-depth background material, lecture notes/slides, numerical implementations that are to ultimately be used in 22.213

Contribute to Real Analysis Project (Safety Case for Re-Licensing)

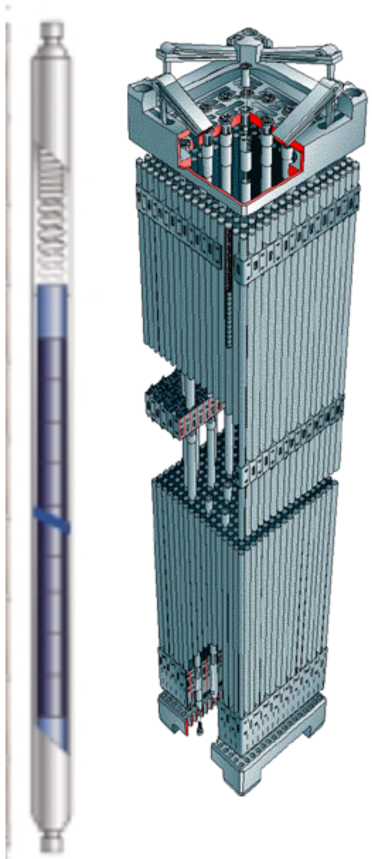


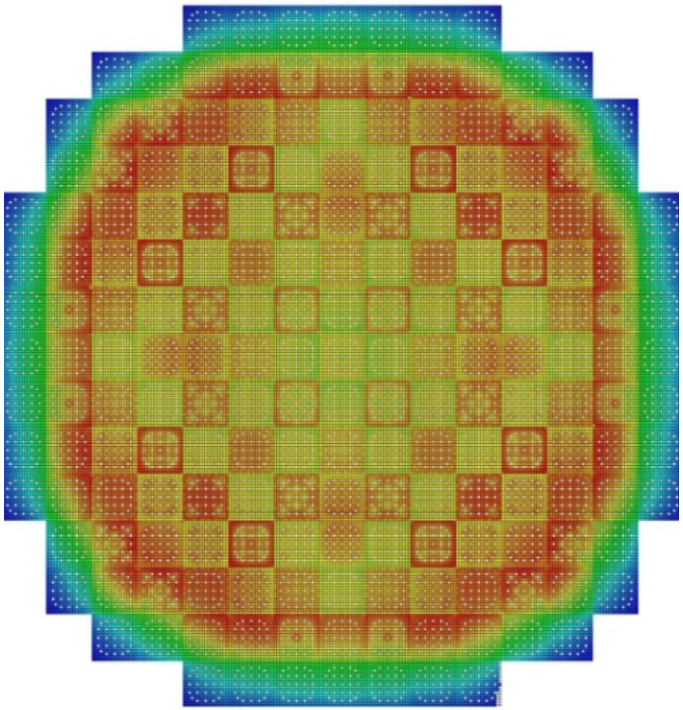


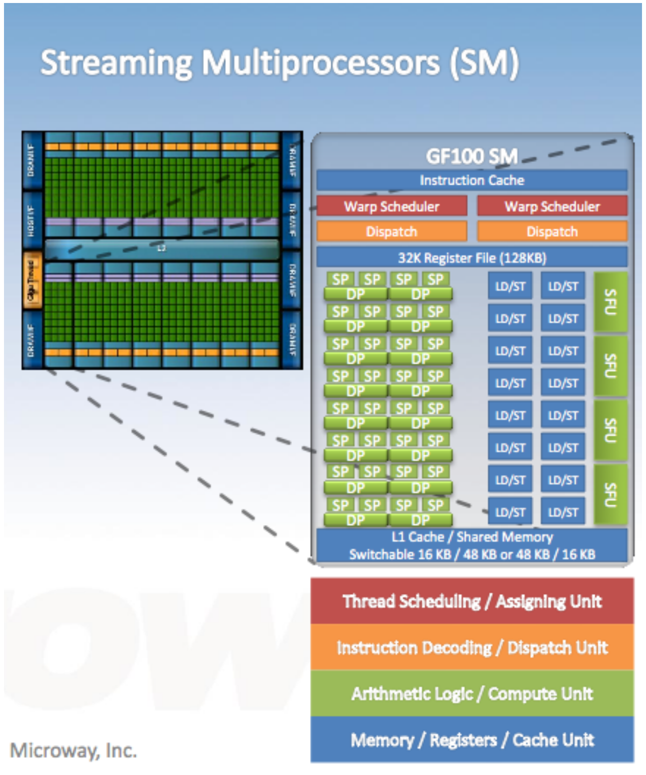
CESAR: DOE's Office of Science

Center For Exascale Simulations of Advanced Reactors

Argonne NATIONAL LABORATORY







OAK RIDGE National Laboratory

Lawrence Livermore National Laboratory

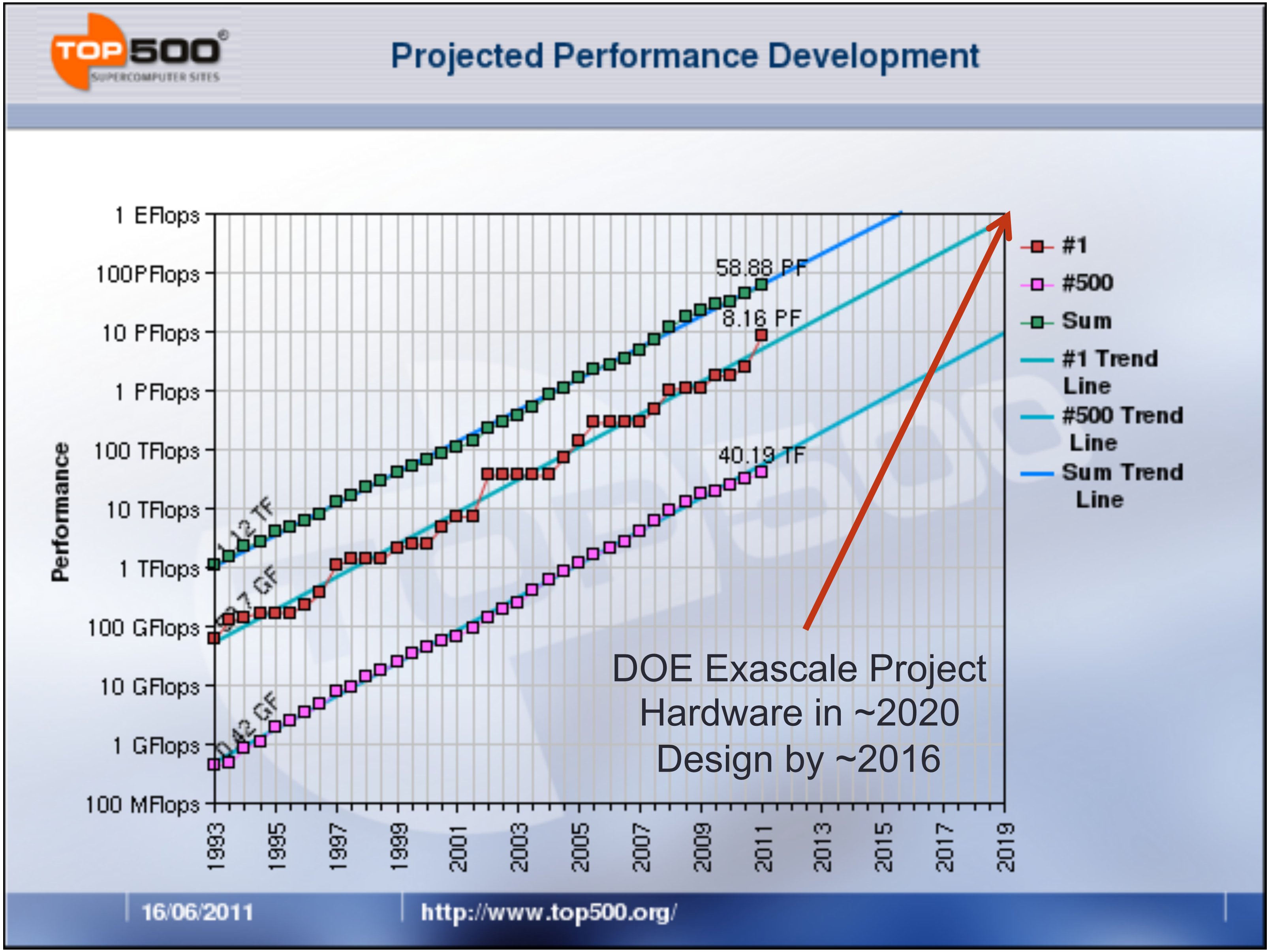
Los Alamos NATIONAL LABORATORY EST. 1943

Pacific Northwest NATIONAL LABORATORY

TEXAS A&M UNIVERSITY

RICE

Methods/Algorithms May Not Be Machine Independent



Which Methods Will Win?

- Nodal diffusion methods can not accommodate spatial mesh refinement.
- Fine-mesh deterministic transport methods require either huge memory or massive inter-processor/inter-node communications bandwidth.
- Monte-Carlo has yet to be used for any real transient analysis.
- Coupled high-fidelity neutronics/fluids methods have yet to really be implemented and used for large scale LWR analysis (full-core) - except perhaps MC21.
- Data requirements for full temperature dependence of nuclear cross section data are only now being explored.
- The next few years will be critical for selecting methods that live for decades.

Let's Build a Course

22.213 (22.S904) Calendar					
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9	3-Oct	Quasi-Static Time-Integration and Synthesis Methods	Smith		PSET # 4: PKE Time Step Control
	8-Oct	Columbus Holiday (8th and 9th)			
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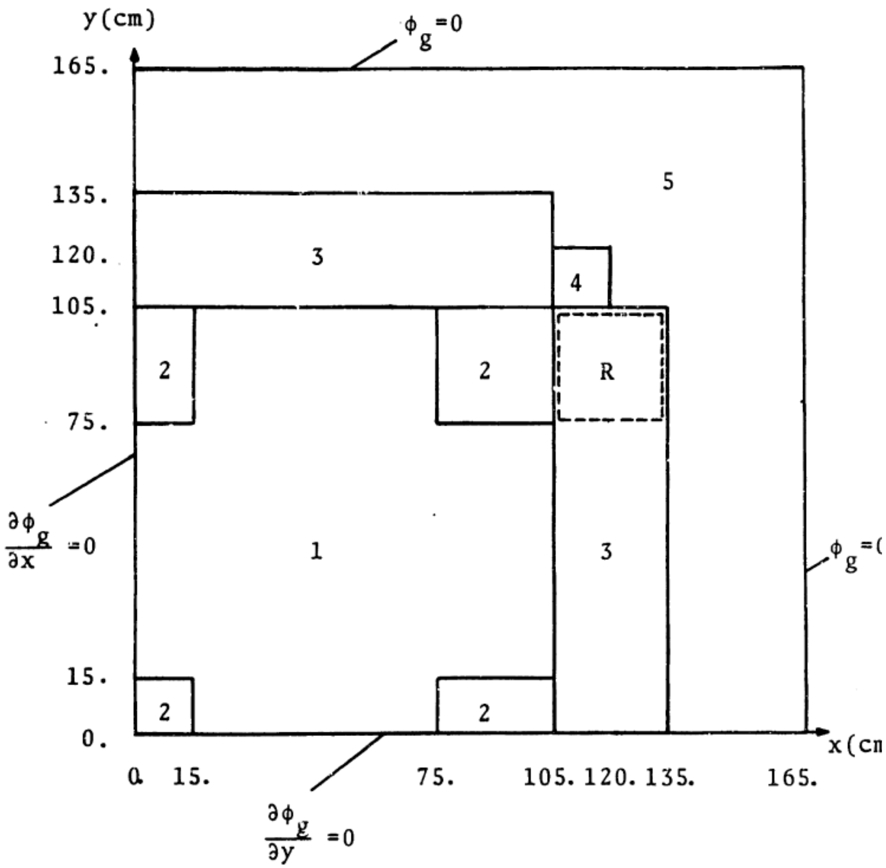
Focus Problem: 2D (or 3D?) LRA

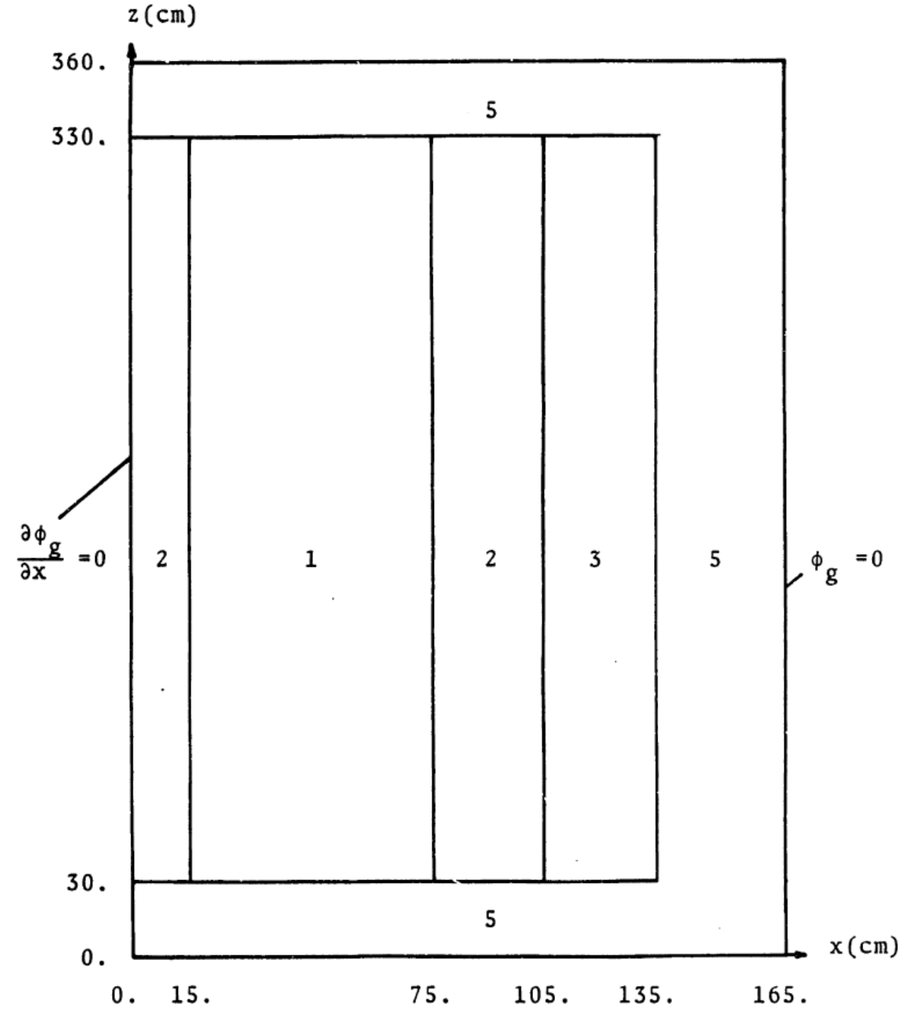
A4.1 THE LRA BWR KINETICS BENCHMARK PROBLEM

Geometry:

Quadrant of Reactor Horizontal Cross Section



Vertical Cross Section, y = 0



LRA with Adiabatic Feedback

Material Properties

Composition*	Group, g	D_g (cm)	Σ_{a_g} (cm^{-1})	$\nu\Sigma_{f_g}$ (cm^{-1})	Σ_{21} (cm^{-1})
1	1	1.255	0.008252	0.004602	0.02533
	2	0.211	0.1003	0.1091	
2	1	1.268	0.007181	0.004609	0.02767
	2	0.1902	0.07047	0.08675	
3	1	1.259	0.008002	0.004663	0.02617
	2	0.2091	0.08344	0.1021	
4	1	1.259	0.008002	0.004663	0.02617
	2	0.2091	0.073324	0.1021	
5	1	1.257	0.0006034	0.0	0.04754
	2	0.1592	0.01911	0.0	

* Axial buckling of 10^{-4} cm^{-2} for all compositions in 2-D problem

$\chi_1 = 1.0$, $\chi_2 = 0.0$

$\nu = 2.43$

$v_1 = 3.0 \times 10^7$ cm/sec

$v_2 = 3.0 \times 10^5$ cm/sec

Delayed Neutron Data:

Family, d	β_d	λ_d (s^{-1})
1	0.0054	0.0654
2	0.001087	1.35

Adiabatic Feedback Data:

$$\alpha_1[\Sigma_f(\underline{r},t)][\phi(\underline{r},t)] = \frac{\partial}{\partial t} T(\underline{r},t) \; ; \quad \alpha_1 = 3.83 \times 10^{-11} \text{ °K cm}^3$$

$$\Sigma_{a_1}(\underline{r},t) = \Sigma_{a_1}(\underline{r},0)\{1 + \alpha_2(\sqrt{T(\underline{r},t)} - \sqrt{T_0})\} \; ;$$

$$\alpha_2 = 2.034 \times 10^{-3} \text{ °K}^{-\frac{1}{2}}$$

$$T_0 = 300\text{°K}$$

Energy Conversion Factor:

$$\text{Power} = \varepsilon \int_{V_{core}} [\Sigma_f(\underline{r},t)][\phi(\underline{r},t)]\, d\underline{r} \; ;$$

$$\varepsilon = 3.204 \times 10^{-11} \text{ Ws/fission}$$

Transient Initial Conditions:

Mean power density at $t = 0$, 10^{-6} W/cc

Fuel temperature at $t = 0$, 300°K

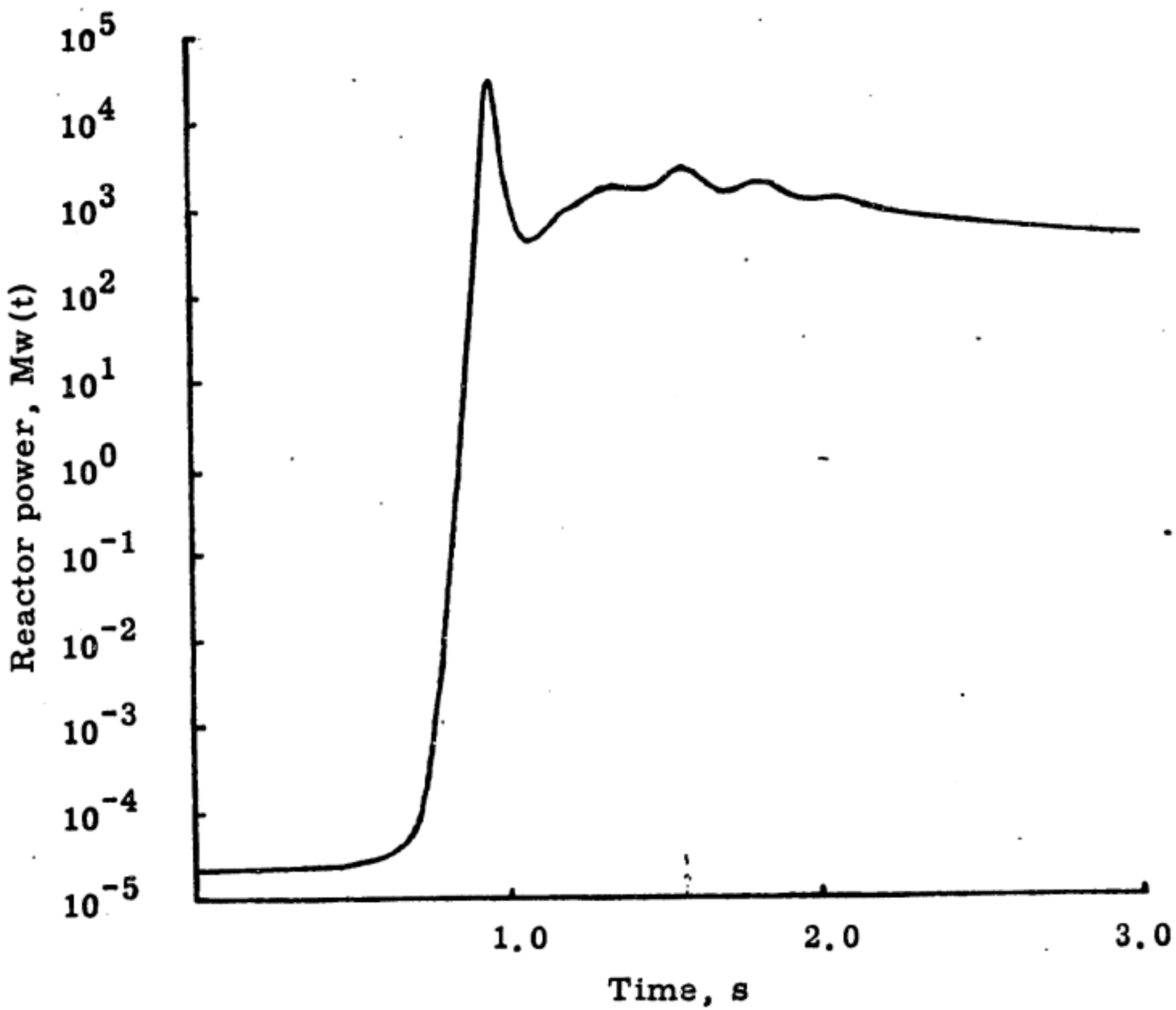
Perturbation:

3-D: Control rod (R) removed with velocity of 150 cm/s

2-D: Control rod composition (R) is given by

$$\Sigma_{a_2}(t) = \begin{cases} \Sigma_{a_2}(0)(1 - 0.0606184 \cdot t) \; ; & t < 2.0 \text{ s} \\ \Sigma_{a_2}(0)(0.8787631) \; ; & t > 2.0 \text{ s} \end{cases}$$

LRA with Adiabatic Feedback



LRA Assembly Powers

Figure A6-3a. 3-D LRA BWR (full-core) transient problem.

NORMALIZED ASSEMBLY POWER DENSITIES AT T = 0.139995E+01
MEAN POWER DENSITY = 0.851563E+02

Y = 11	0.0	0.0	2.803E-01	3.799E-01	6.116E-01	9.862E-01	1.413E+00	2.509E+00	3.568E+00	0.0	0.0
Y = 10	0.0	3.581E-01	4.972E-01	5.465E-01	8.894E-01	1.588E+00	2.018E+00	3.811E+00	6.912E+00	7.379E+00	0.0
Y = 9	2.284E-01	4.312E-01	5.787E-01	4.267E-01	7.012E-01	1.609E+00	1.579E+00	3.257E+00	8.975E+0	1.137E+01	.377E+00
Y = 8	1.988E-01	3.029E-01	2.748E-01	2.511E-01	3.795E-01	6.525E-01	9.247E-01	1.908E+00	4.055E+00	5.826E+00	4.181E+00
Y = 7	1.492E-01	2.176E-01	1.839E-01	1.554E-01	2.101E-01	3.477E-01	5.321E-01	1.057E+00	2.020E+00	2.765E+00	1.984E+00
Y = 6	1.337E-01	2.195E-01	2.369E-01	1.287E-01	1.664E-01	3.734E-01	3.799E-01	7.909E-01	2.048E+00	2.069E+00	1.299E+00
Y = 5	1.008E-01	1.480E-01	1.230E-01	9.049E-02	1.094E-01	1.755E-01	2.402E-01	4.661E-01	8.862E-01	1.135E+00	7.829E-01
Y = 4	8.416E-02	1.246E-01	1.054E-01	8.174E-02	9.665E-02	1.441E-01	1.825E-01	3.075E-01	5.313E-01	6.842E-01	4.768E-01
Y = 3	7.735E-02	.419E-01	1.784E-01	1.093E-01	1.361E-01	2.709E-01	2.170E-01	3.347E-01	7.121E-01	6.141E-01	3.469E-01
Y = 2	0.0	1.104E-01	1.436E-01	1.307E-01	1.646E-01	2.519E-01	2.571E-01	3.678E-01	5.285E-01	4.404E-01	0.0
Y = 1	0.0	0.0	7.866E-02	8.870E-02	1.122E-01	1.536E-01	1.764E-01	2.411E-01	2.796E-01	0.0	0.0
X =	1	2	3	4	5	6	7	8	9	10	11

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Kinetics: Background Knowledge Exam-0

- **Background:**
  - 20 questions with simple answers
  - 15 minutes to complete the exam
  - If you do not understand terminology in the question (as opposed to the answer) **leave blank**
  - There are often no "correct" answers, I am looking for +/- 20% answers
- Exam is not fair: people who have not had material should not know the answers!
- Goal: Answer a few basic questions:
  - How much prior knowledge do some class members have?
  - What concepts are poorly understood?
  - What level of review is needed?
  - What topics can we skip?
- Next class: quickly summarize and understand exam results

Assignment for Next Class

- Review basic physics: e.g., Neutron Physics by Paul Reuss fro PKEs

- Make sure you are can use MATLAB or some low-level language:
  - Logical tests
  - Array-based computations
  - Simple loops
  - Informative plots
  - Think physics!

- Have fun and welcome back!