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Surviving Scientific Academia ... and Beyond

Jeremy Lloyd Conlin

Los Alamos National Laboratory

February 3, 2016

Abstract

It's been 16 years since I first took a physics class at Weber State University. Since then, I've survived graduate school in Nuclear Engineering, and a postdoc appointment doing nuclear nonproliferation. Now I'm a Technical Staff Member at Los Alamos National Laboratory working with nuclear data, the physics behind the numerical simulations of nuclear reactors and nuclear weapons.

Along the way, I've learned a few things. First, scientific computing is *everywhere* in science. If you are not writing codes, you will be analyzing their output, and generally there will be more output than a human can correctly and accurately interpret in a timely manner. Second, a career in science or engineering can be very rewarding with opportunities to collaborate with and generate friendships with very bright people from all over the world.

Public Relations or Science?

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PHYS 1030 Introduction to Astronomy—Adam Johnston

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PHYS 2210 Physics for Scientists and Engineer—Brad Carroll

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- Ott Planetarium—Jon Sohl
- Atomic Force Microscope—Colin Inglefield
- Beishline Computer Application Fellowship
 - Using Voronoi diagrams to model micro-crystalline silicon growth
 - Writing computer code to solve scientific problems

- Condensed Matter Physics
 - Arizona
 - Colorado
 - Minnesota
 - North Carolina State
 - Michigan State

- Condensed Matter Physics
 - Arizona
 - Colorado
 - Minnesota
 - North Carolina State
 - Michigan State
- Medical Physics

- Condensed Matter Physics
 - Arizona
 - Colorado
 - Minnesota
 - North Carolina State
 - Michigan State
- Medical Physics
 - Michigan—
Nuclear Engineering

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Nuclear Engineering



Nuclear Engineering and Radiological Sciences

#1 Nuclear Engineering program in the US

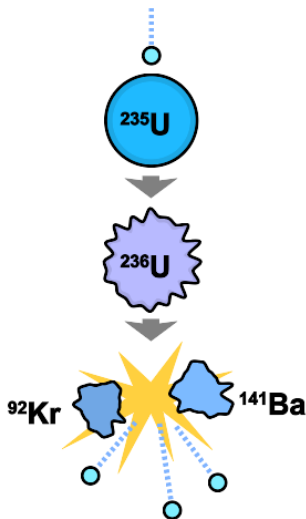
Nuclear Engineering and Radiological Sciences

#1 Nuclear Engineering program in the US

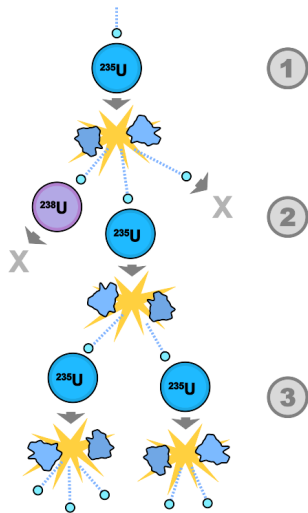
- Neutron transport
- Radiation effects on material
- Health physics
- Plasma physics

Fission

- 1 Neutron collides with ^{235}U nucleus
- 2 Nucleus (temporarily) becomes ^{236}U
- 3 Nucleus splits into
- 4 μ neutrons released
- 5 180 MeV released



Fission Chain Reaction



Fission occurs releasing μ neutrons

- 1 Leak out
- 2 Collide
- 3 Scatter
- 4 Fission

Particle Transport

Boltzmann Transport Equation:

$$\Omega \cdot \nabla \psi(\mathbf{r}, \Omega) + \Sigma_t \psi(\mathbf{r}, \Omega) = \frac{\Sigma_s}{4\pi} \int \psi(\mathbf{r}, \Omega) d\Omega + \frac{1}{k} \frac{\nu \Sigma_f}{4\pi} \int \psi(\mathbf{r}, \Omega) d\Omega$$

Particle Transport

Boltzmann Transport Equation:

$$\underbrace{\Omega \cdot \nabla \psi(\mathbf{r}, \Omega)}_{\text{leakage=L}} + \underbrace{\Sigma_t \psi(\mathbf{r}, \Omega)}_{\text{collision=C}} = \underbrace{\frac{\Sigma_s}{4\pi} \int \psi(\mathbf{r}, \Omega) d\Omega}_{\text{scatter=S}} + \underbrace{\frac{1}{k} \frac{\nu \Sigma_f}{4\pi} \int \psi(\mathbf{r}, \Omega) d\Omega}_{\text{fission=F}}$$

Particle Transport

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Operator Form:

$$(\mathbf{L} + \mathbf{C} - \mathbf{S})\psi = \frac{1}{k}\mathbf{F}\psi$$
$$\mathbf{T}\psi = \frac{1}{k}\mathbf{F}\psi$$

Particle Transport

Boltzmann Transport Equation:

$$\underbrace{\Omega \cdot \nabla \psi(\mathbf{r}, \Omega)}_{\text{leakage=L}} + \underbrace{\Sigma_t \psi(\mathbf{r}, \Omega)}_{\text{collision=C}} = \underbrace{\frac{\Sigma_s}{4\pi} \int \psi(\mathbf{r}, \Omega) d\Omega}_{\text{scatter=S}} + \underbrace{\frac{1}{k} \frac{\nu \Sigma_f}{4\pi} \int \psi(\mathbf{r}, \Omega) d\Omega}_{\text{fission=F}}$$

Operator Form:

$$\begin{aligned} (\mathbf{L} + \mathbf{C} - \mathbf{S})\psi &= \frac{1}{k} \mathbf{F}\psi \\ \mathbf{T}\psi &= \frac{1}{k} \mathbf{F}\psi \end{aligned}$$

Define:

$$\begin{aligned} \mathbf{v} &\equiv \mathbf{F}\psi \\ \mathcal{A} &\equiv \mathbf{F}\mathbf{T}^{-1} \end{aligned}$$

$$\mathcal{A}\mathbf{v} = k\mathbf{v}$$

Eigenvalue Problem

$$\mathcal{A}v = kv$$

\mathcal{A} : Linear operator k : eigenvalue v : eigenvector

Multiplication Factor

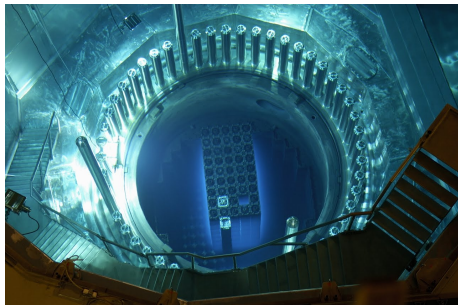
Eigenvalue Problem

$$\mathcal{A}v = kv$$

\mathcal{A} : Linear operator k : eigenvalue v : eigenvector

$k =$ multiplication factor

- $k = 1$ critical



Multiplication Factor

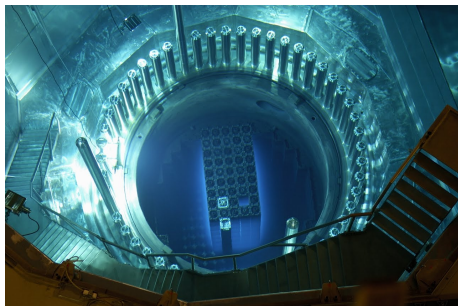
Eigenvalue Problem

$$\mathcal{A}v = kv$$

\mathcal{A} : Linear operator k : eigenvalue v : eigenvector

k = multiplication factor

- $k = 1$ critical
- $k < 1$ sub-critical



Multiplication Factor

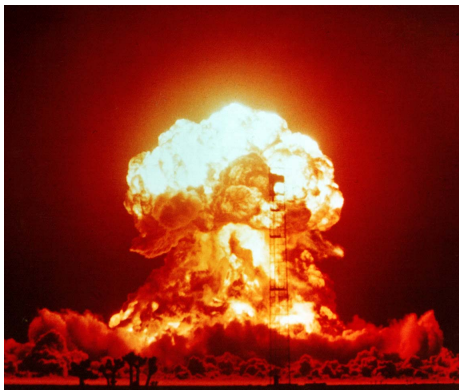
Eigenvalue Problem

$$\mathcal{A}v = kv$$

\mathcal{A} : Linear operator k : eigenvalue v : eigenvector

k = multiplication factor

- $k = 1$ critical
- $k < 1$ sub-critical
- $k > 1$ super-critical



Calculating Eigenvalues

Monte Carlo Neutron Transport

Power Method

- Only fundamental (largest) eigenvalue
- Convergence proportional to dominance ratio

$$DR = \lambda_2/\lambda_1$$

Calculating Eigenvalues

Monte Carlo Neutron Transport

Power Method

- Only fundamental (largest) eigenvalue
- Convergence proportional to dominance ratio

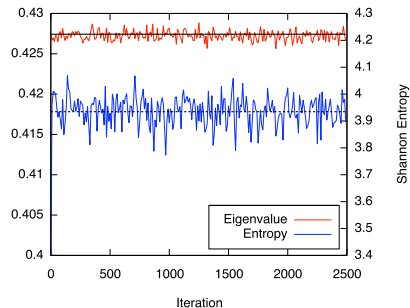
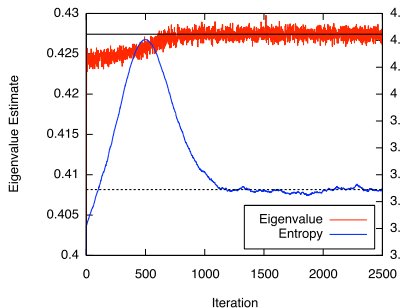
$$DR = \lambda_2/\lambda_1$$

Arnoldi's Method

- Multiple eigenvalues
- Faster convergence

Eigenvalue Convergence

Monte Carlo Neutron Transport

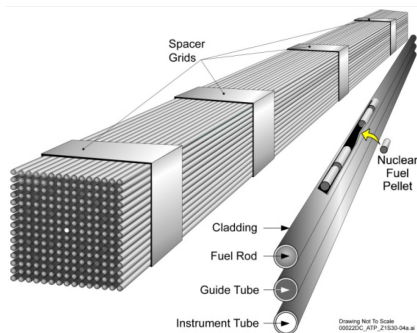


Non-proliferation of Nuclear Material from Spent Nuclear Fuel

Objective

Quantify the **plutonium mass** in spent fuel assemblies and identify any plutonium diversion.

- Non-destructive assay—can't destroy the nuclear material
- 14 techniques under investigation
- Simulation library 64 models of spent nuclear fuel
- **> 1000 simulations**



Los Alamos National Laboratory Codes

- Model nuclear reactions
 - Nuclear reactors
 - Nuclear weapons
 - Radiation protection
- Climate modeling
- Astrophysics
- Bioscience
- Chemistry
- ...

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 - 4–8 GiB RAM, 8×10^9 B
- World's largest supercomputers
 - > 2 PiB RAM, 2×10^{15} B

Los Alamos National Laboratory Codes

- Model nuclear reactions
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- ...
- Desktop computers
 - 4–8 GiB RAM, 8×10^9 B
 - 2–4 CPUs, ~ 3 Giflop
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 - > 2 PiB RAM, 2×10^{15} B
 - $> 600k$ CPUs, > 80 Piflop

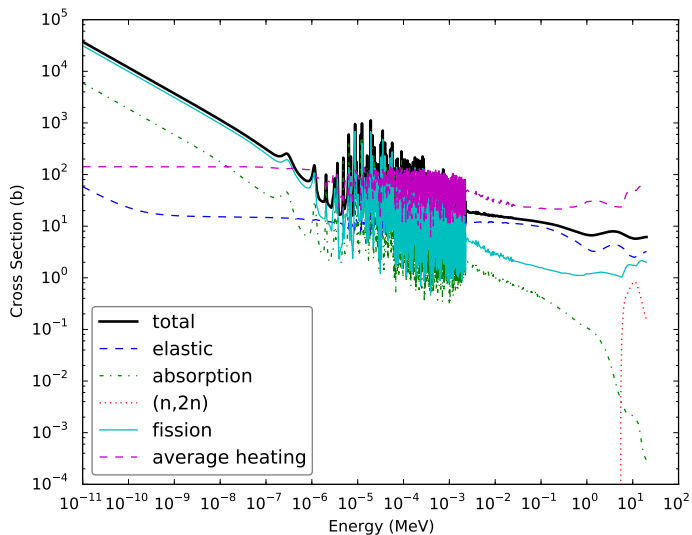
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- ...
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 - 1–2 TiB file system
- World's largest supercomputers
 - > 2 PiB RAM, 2×10^{15} B
 - $> 600k$ CPUs, > 80 Piflop
 - > 80 PiB file system

Los Alamos National Laboratory Codes

- Model nuclear reactions
 - Nuclear reactors
 - Nuclear weapons
 - Radiation protection
- Climate modeling
- Astrophysics
- Bioscience
- Chemistry
- ...
- Desktop computers
 - 4–8 GiB RAM, 8×10^9 B
 - 2–4 CPUs, ~ 3 Giflop
 - 1–2 TiB file system
 - 65 W to 250 W
- World's largest supercomputers
 - > 2 PiB RAM, 2×10^{15} B
 - $> 600k$ CPUs, > 80 Piflop
 - > 80 PiB file system
 - < 10 MW power

Nuclear Data



Nuclear Data Libraries

Evaluation data

- Created by experimentalists and theorists
- Compiled by **CSEWG**—Cross Section Evaluation Working Group
- Released by **NNDC**—National Nuclear Data Center, Brookhaven National Laboratory
- Processed by NJOY to application files

Nuclear Data Libraries

LANL

MENDF70

- 393 isotopes
- 1 temperature
- multi-group energy
- 4.7 GiB

Nuclear Data Libraries

LANL

MENDF70

- 393 isotopes
- 1 temperature
- multi-group energy
- 4.7 GiB

ENDF71x

- 423 isotopes
- 7 temperatures
- continuous energy
- 16 GiB

Nuclear Data Libraries

LANL

MENDF70

- 393 isotopes
- 1 temperature
- multi-group energy
- 4.7 GiB

ENDF71x

- 423 isotopes
- 7 temperatures
- continuous energy
- 16 GiB

MENDF71x

- 423 isotopes
- 1 temperature
- multi-group energy
- 7.0 GiB

Nuclear Data Libraries

LANL

- MENDF70
- 393 isotopes
 - 1 temperature
 - multi-group energy
 - 4.7 GiB

- ENDF71x
- 423 isotopes
 - 7 temperatures
 - continuous energy
 - 16 GiB

- MENDF71x
- 423 isotopes
 - 1 temperature
 - multi-group energy
 - 7.0 GiB

- MT71x
- 423 isotopes + 25 elementals
 - 23 temperatures
 - multi-group and continuous energy
 - 211 GiB

Nuclear Data Libraries

Verification and Validation

Verification^a

Check that a product. . . meets a set of design specifications.

Validation^a

Ensure a product. . . results in a product. . . that meets the operational needs of the user.

Nuclear Data Libraries

Verification and Validation

Verification^a

Check that a product... meets a set of design specifications.

Verification = format

Validation^a

Ensure a product... results in a product... that meets the operational needs of the user.

Validation = physics

^ahttps://en.wikipedia.org/wiki/Verification_and_validation

How Does Science Progress?

Travel

Travel

- Conferences:
San Diego; Washington, DC;
New Orleans, LA; Keystone,
CO; Atlanta, GA; Hollywood,
FL; Las Vegas, NV
- Collaboration:
Livermore, CA; Oak Ridge, TN;
Brookhaven, NY;
- Learning:
Nevada Test Site; Malmstrom
Air Force Base, MT

Travel

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San Diego; Washington, DC;
New Orleans, LA; Keystone,
CO; Atlanta, GA; Hollywood,
FL; Las Vegas, NV
- Collaboration:
Livermore, CA; Oak Ridge, TN;
Brookhaven, NY;
- Learning:
Nevada Test Site; Malmstrom
Air Force Base, MT
- Sao Paulo, Brazil (2011)
- Tokai, Japan (2013)
- Paris, France (2014, 2015, 2016)
- Vienna, Austria (2015, 2016)
- London, England (2016)
- Bruges, Belgium (2016)

Conclusion

- Gain experience
 - Undergraduate research
 - Summer internships
 - Extracurricular interests and classes
- Don't be afraid of graduate school
- Find someone who supports and encourages you
- Learn from mentors
- Do things better than before
- Computing is required in **all** areas of science—better learn it
- Write papers
- Enjoy the journey!