



Overview of Technical Area V, Annular Core Research Reactor, Internships and Research, and GenSpec[®]

Presented to the UNM ANS Student Chapter

Danielle Redhouse

Applied Nuclear Technologies

November 8, 2017

Quick About Me

- Attended UNM from 2008 – 2015 (B.S. Nuclear Engineering)
- Previous UNM ANS secretary
- Initially majored in Classical Musical Performance
- Worked at SNL since 2012
- DoE Secretary's Achievement Award (2016)
- Sandia Master's Fellow Nomination (2016)
- Attended Texas A&M from 2015-2017 (M.S. Nuclear Engineering)

- Grew up in Albuquerque
- Traveling is my hobby

Career Projects/Research

(1/13-3/15) Nuclear Materials Management Department (01386)

- Worked with WIPP, LANL, Emergency Operations/ IT Team (42362), and Department of Homeland Security (DoHS)

(3/15-8/15) Waste Management and Pollution Prevention (04144)

- Re-wrote and updated the waste management process for gamma spectrum analysis (migration from Excel to C)

(8/15-1/16) Applied Nuclear Technologies (01384)

- Programming and MFP Nomination

(1/16-8/17) Master's Fellowship Participant (Texas A&M University)

- Thesis: *Uncertainty quantification of a genetic algorithms for neutron energy spectrum adjustment*

(8/17- Present) R&D S&E Nuclear Engineer

- Lead Programmer for GenSpec UQSuite® and Co-Lead Programmer for GenSpec®

Most of my time at SNL has been at SNL's TA-V

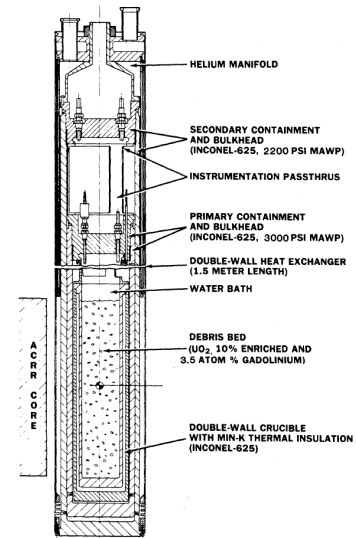
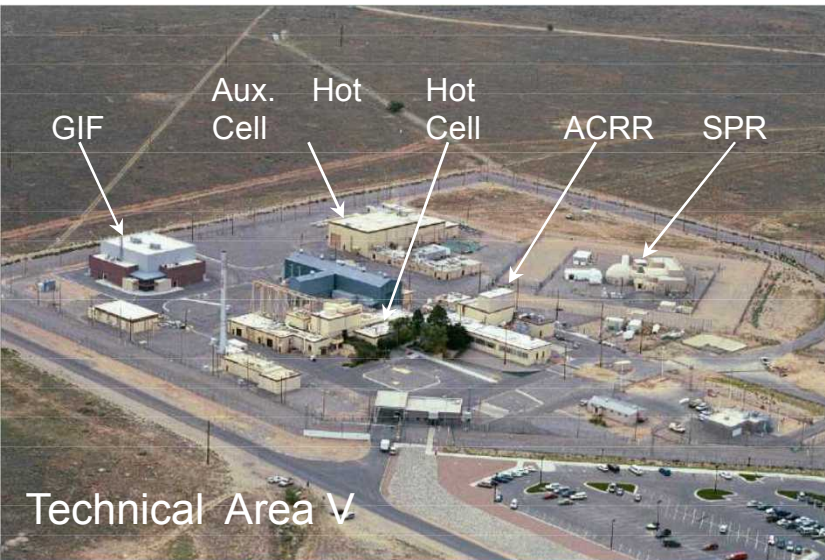
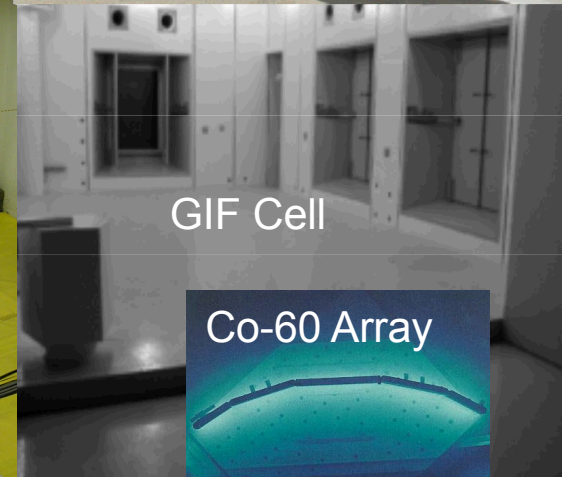


FIGURE 1 DCC-2 EXPERIMENT PACKAGE

Sandia National Labs - Nuclear Facilities - TA-V



- Radiation Simulation
- Dosimetry – n/γ
- Reactor Safety
- Fuels Testing



Co-60 Array

TA-V Facilities Currently Operating



Annular Core Research Reactor



Sandia Pulse Reactor
and Critical Experiments



Radiation Metrology Laboratory



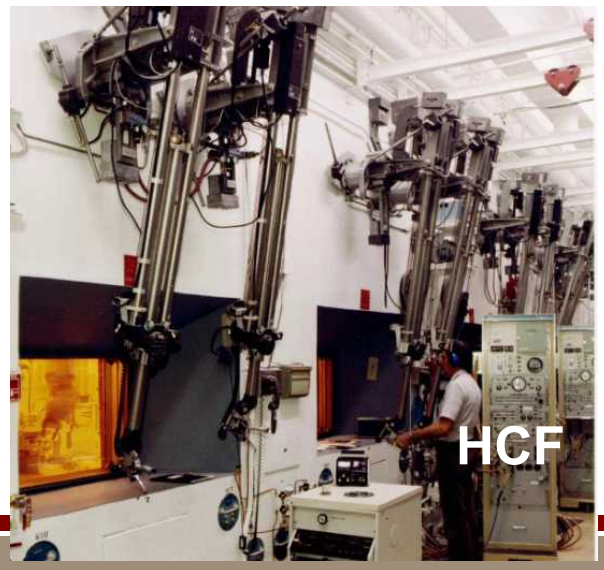
Gamma Irradiation Facility



Auxiliary Hot Cell Facility



Hot Cell Facility



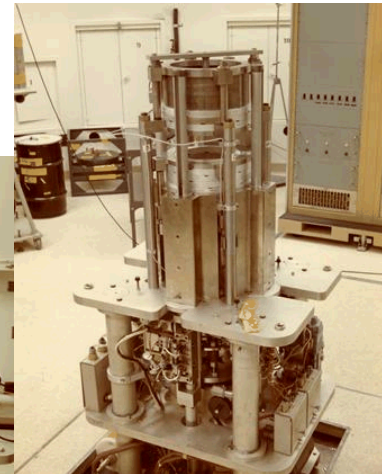
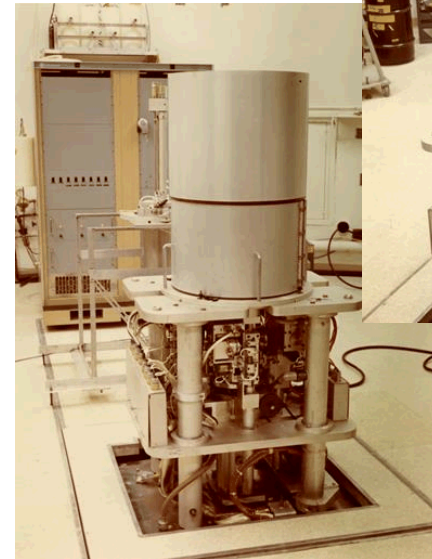
TA-V History

- TAV was constructed in 1959 as part of the Nuclear Airplane Project
 - Sandia Pulse Reactor (SPR-I) – 1961
 - Sandia Pulse Reactor (SPR-II) - 1967
 - Sandia Nuclear Assembly Reactor (SNARE) – 1962
 - Sandia Engineering Reactor (SER) – 1963
 - Annular Core Pulse Reactor (ACPR) 1967

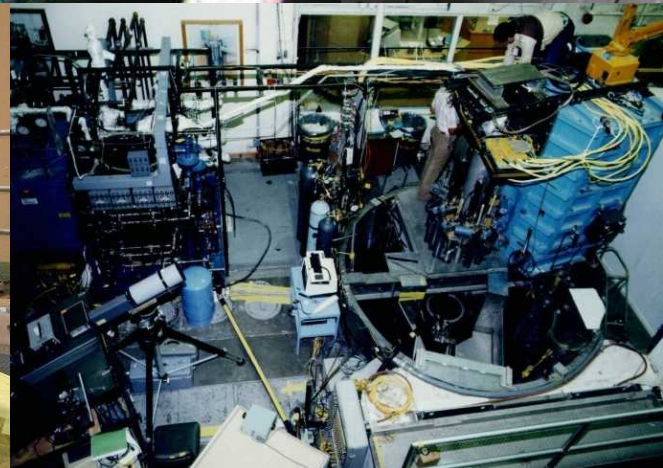
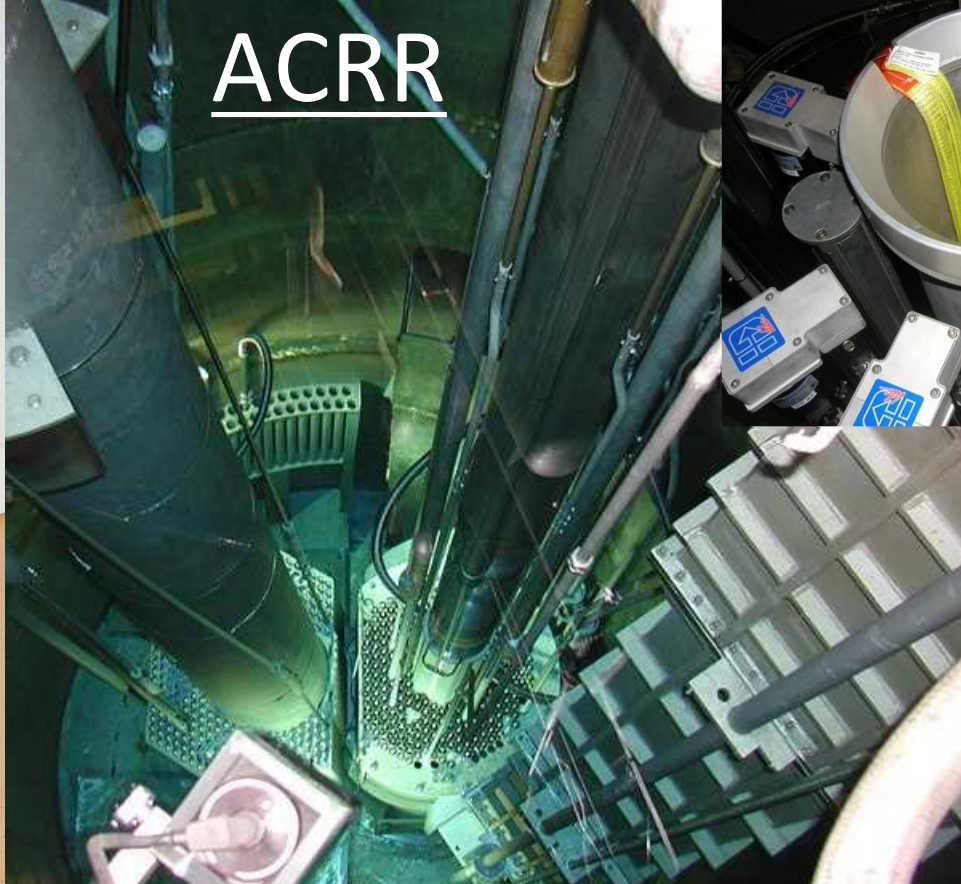
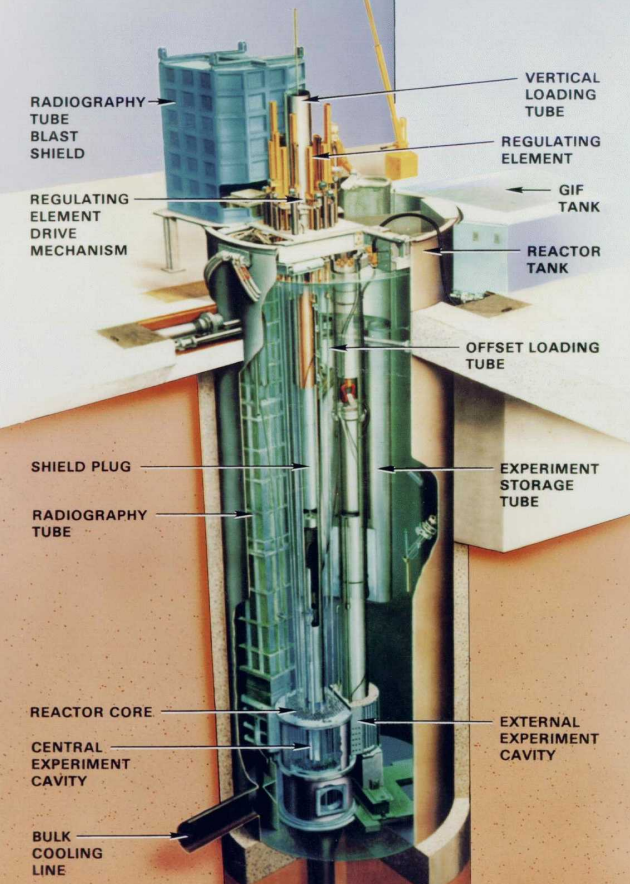


TA-V Recent History

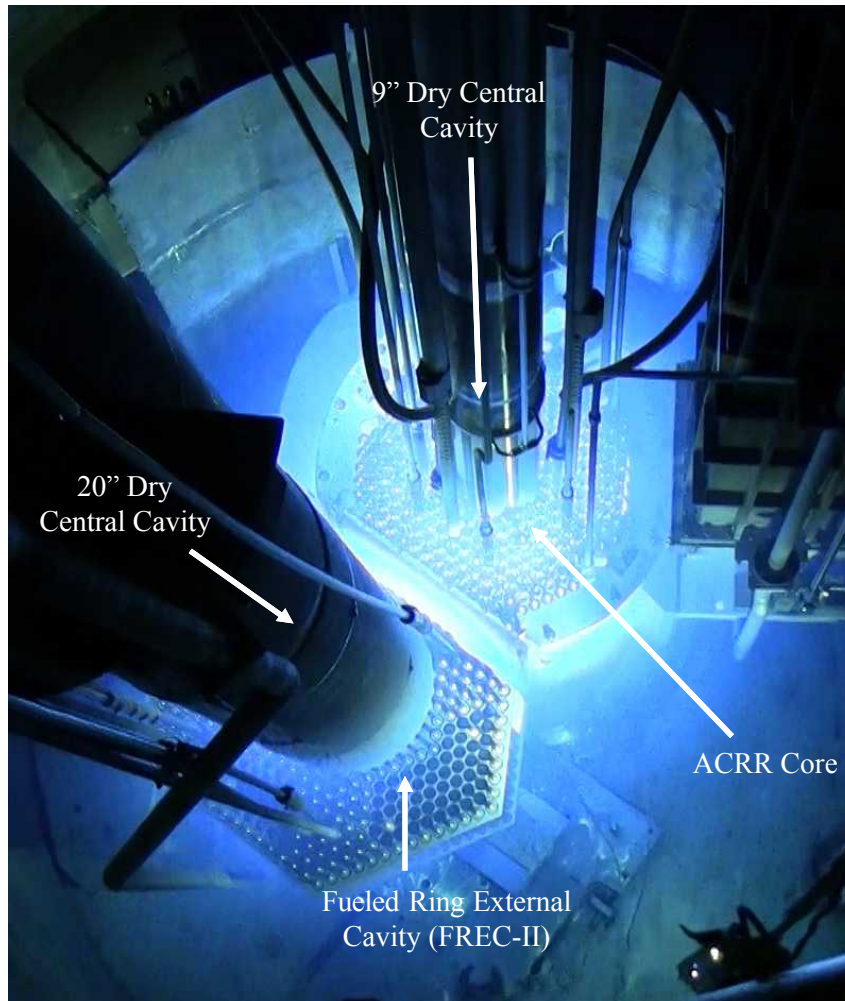
- TAV continued to build on its nuclear reactor success through the '70s and '80s
 - Sandia Pulse Reactor (SPR-III) - 1976
 - Annular Core Research Reactor (ACRR) – 1978
 - Critical Experiment-Space Nuclear Thermal Power (SNTP-CX) - 1989
 - ACRR-Fueled Ringed External Cavity (FREC-II) – 1988



ACRR



ACRR Description



ACRR and FREC-II

- 236 $\text{UO}_2\text{-BeO}$ fueled elements
1.5 in (3.8 cm) dia. x 20.5 in (52 cm)
100 g U-235 per element – 35% enriched
- Operating Power level
2-4 MW_{th} Steady-State Mode
300 MJ Pulse Mode (6 ms FWHM)
- Dry cavity 9 in (23 cm) diameter
Extends full length of pool through core
Neutron Flux $4\text{e}13$ n/cm²-s at ~2 MW
Neutron Fluence $6\text{e}15$ n/cm² at ~300 MW
- Epithermal/Fast Spectrum
Flux can be tailored for desired energy spectrum
- Open-pool type reactor
Core cooled by natural convection
Pool cooled by HX and cooling tower
- FREC-II uses previous ACPR fuel
TRIGA type (UZrH)
Dry cavity 20 in (51 cm) diameter
- Reactor used for short duration power runs, pulses, and transients

ACRR Pulse and ACRR-FRECI Coupled Pulse

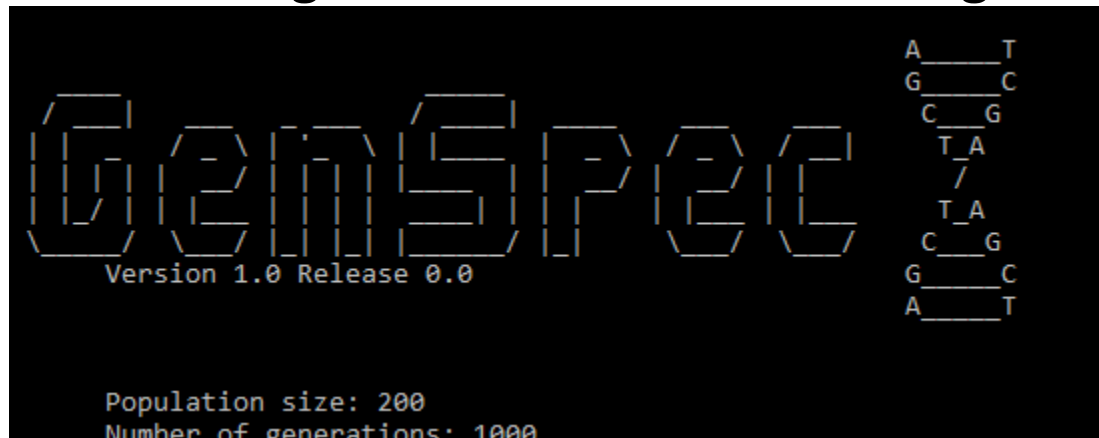
Single Pulse Mode



Coupled Pulse Mode



- GenSpec[®] is program that uses a genetic algorithm for neutron energy spectrum adjustment
 - This minimizes the differences and uncertainties between a calculated and measured neutron spectra
 - Why is it cool? I helped write it on a whim, and as it turns out it works
 - In the field of spectrum adjustment – a new method has not been developed in a while (~1970s)
- But first, some background on what I'm talking about...



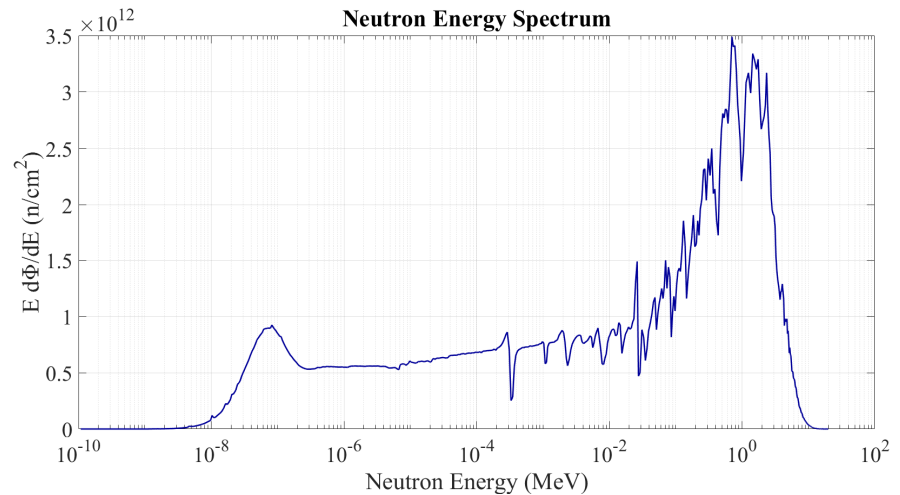
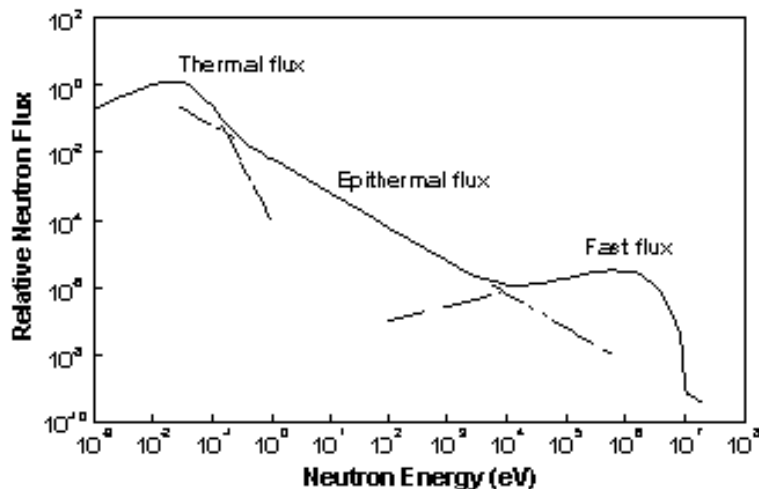
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GENSPEC
Version 1.0 Release 0.0

Population size: 200
Number of generations: 1000

A____T
G____C
C____G
T_A
/
T_A
C____G
G____C
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Background: Neutron Energy Spectra

- Neutron Energy Spectra is the characterization of the energy across the population of neutrons in a reactor.
- Most often, reactors will have similar features
 - Fission/Watt's Peak
 - Maxwellian Thermal Peak
 - Epithermal Region
 - Resonance Region



Background: Neutron Energy Spectra cont.

Why do I care?

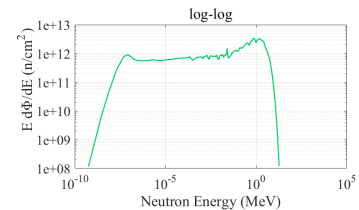
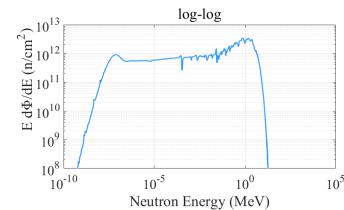
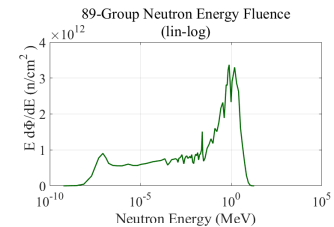
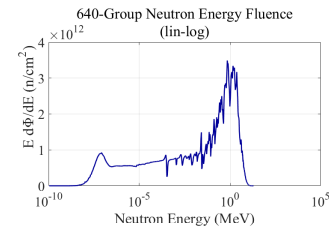
- For experiments and component testing, information about the field where objects are being tested is kinda important.
- Without characterization, only results from neutronics codes would be available – with little information on uncertainty.
 - And numbers without statistics are worthless

- How do you obtain a Spectrum?

- Calculating a spectrum – fairly easy with computers

$$I = \int_0^{\infty} \phi(E)R(E)dE$$

- Physically Measuring a spectrum – How much extra space do you have...



Background: Spectrum Measurements

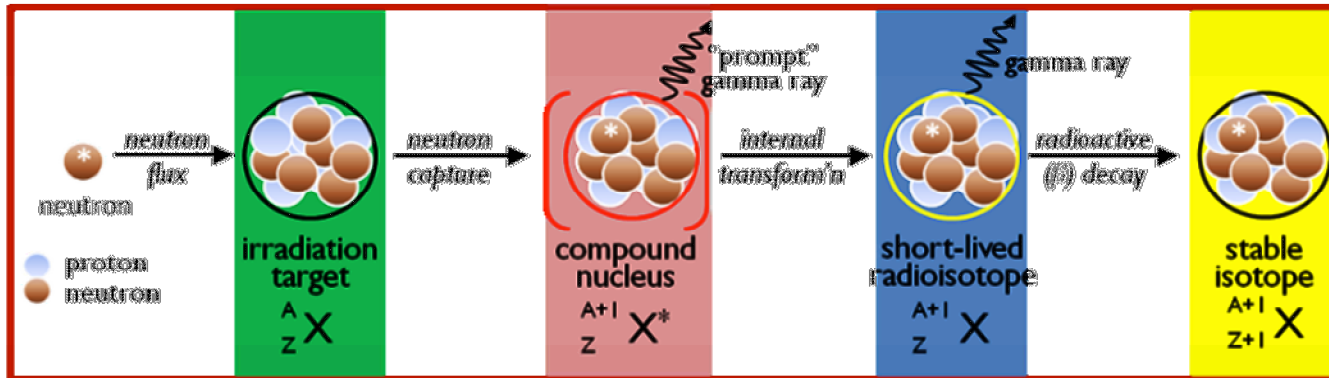
- Two common methods for physical measurements:

- Bonner Spheres

- Effective – Cumbersome, Expensive
- Limited by the size of detector and sphere

- Neutron Activation Analysis

- It works – Sensitive, Cost-Effective
- Limited by the number of Foils
- This process is known as spectrum “unfolding”



- Using the unfolding method, simplifies the computational equation to:

$$I \approx \sum_{i=1}^n \phi_i(E) R_i(E) \Delta E_i$$

But this problem is under-determined and will have a low-resolution, which is not good statistically

Neutron Activation Foils and Setup

- Activation Foils
 - 23 Different Foils, 42 Reactions

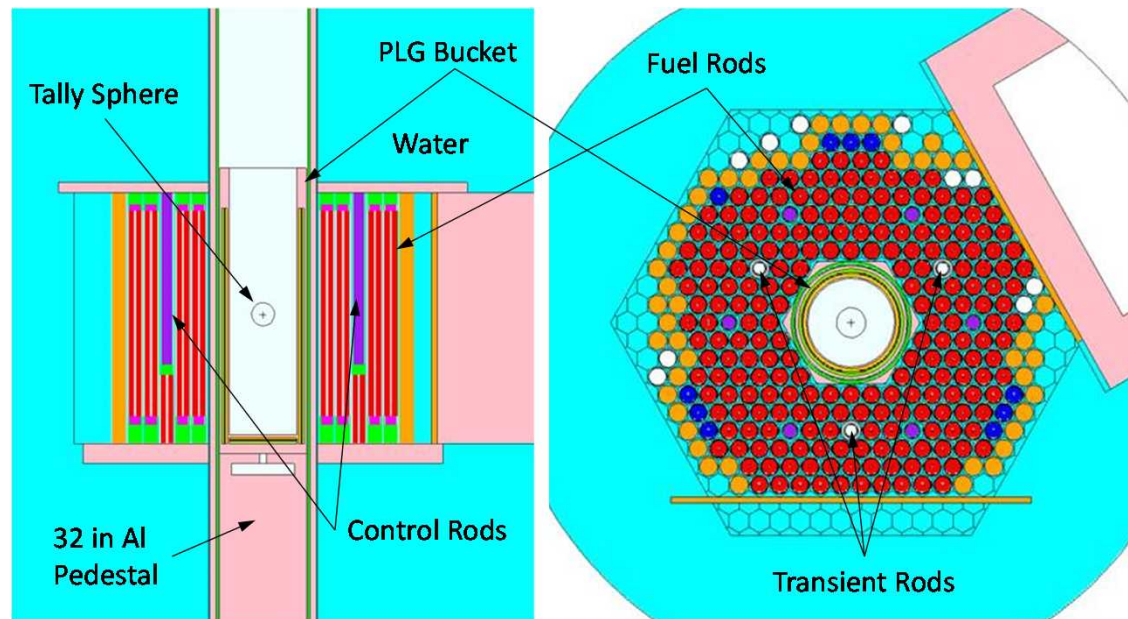


But this problem is under-determined and will have a low-resolution, which is not good statistically

Background: Spectrum Adjustment

- *Why don't I just calculate the spectrum from MCNP?*
 - Confidence in the Model? “All models are wrong, but some are useful”
 - These constantly vary in reality:

- Temperature
- Density (ρ)
- Cross-sections (σ_{cx})
- Geometry

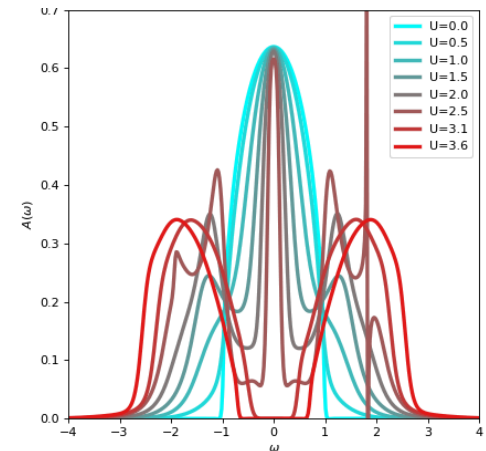


- We want a spectrum with a higher resolution than possible through *both* experimental and calculational measurements
- We adjust the calculated spectrum to bring it into agreement with measure “unfolded” spectra

Background: Spectrum Adjustment

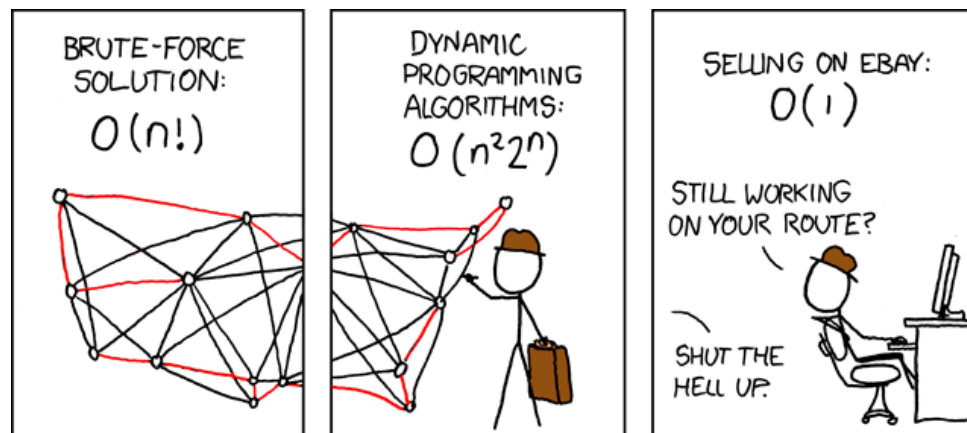
- Two Common Methods – Perturbation and Statistical Least Squares

- Both these methods have issues and are antiquated
- Unrealistic spectral artifacts
- Pure mathematic solutions
- Strive for better statistics – not better answers (*what?*)
- High iterations lead to an over perturbed spectrum
- They are written in bloated FORTRAN codes (trust me, I'm rewriting them now)



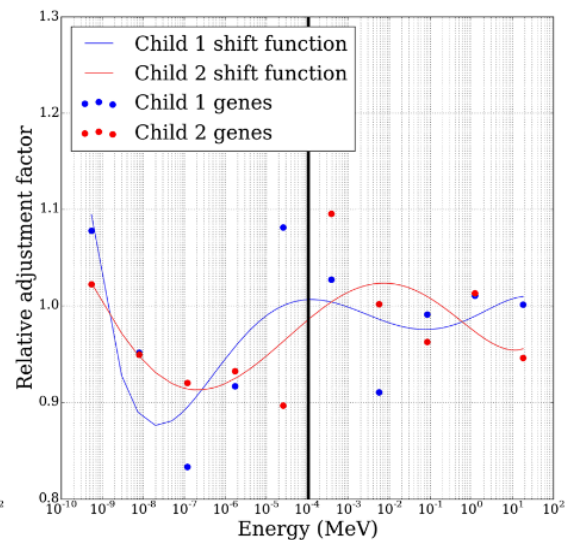
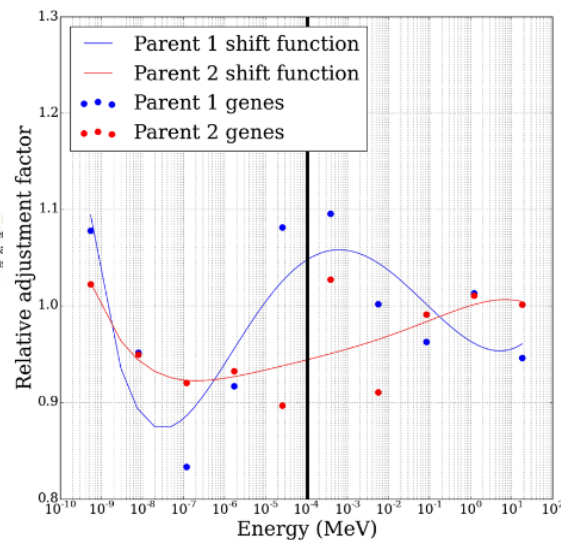
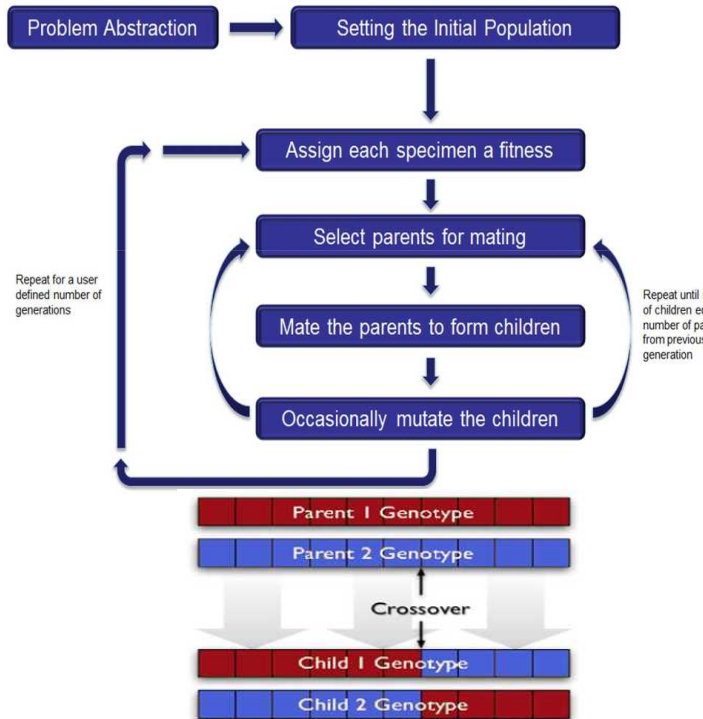
- Hey, why don't we write a new code?

“What do you mean you are going to *mate* two spectra?”

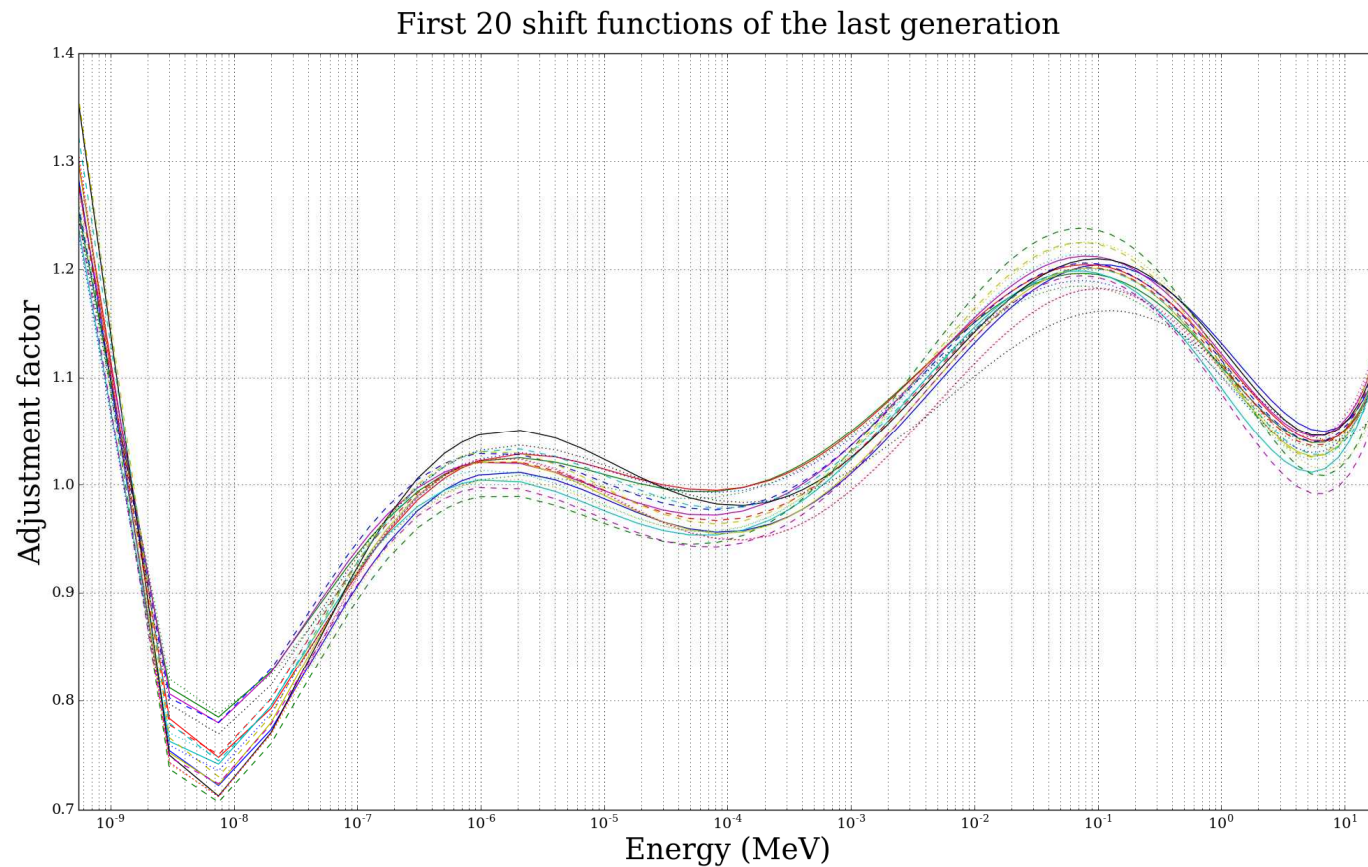


- GenSpec[®] optimizes the spectrum by minimizing the differences between a calculated and a measure spectrum
 - Apply a genetic algorithm – Population, Generations, Mutation
 - Designate a “fitness” to spectra
 - Recombine (mate) the fittest spectra

$$f = C - \sum_{i=1}^m \frac{\left| \left\{ \sum_{j=1}^n \sigma_{j,i} \phi_j \Delta E_j \right\} - r_i \right|}{r_i}$$



- How does GenSpec compare to older methods?
 - It *looks* pretty good! But is this real?



- “Can you go get a MS degree and figure out if this code is producing *real* data?”
- Sure, but what is uncertainty quantification?
 - It tries to determine how likely certain answers are, or how true or reliable a set of data is
- Brute Force Random Sampling
 - Parametric Sensitivity analysis – test the genetic algorithm
 - Build and use Cholesky decomposition
 - Use multivariate random sampling to recreate spectra and cross-sections

$$A = \begin{bmatrix} a_{1,1} & a_{1,2} & \dots & a_{1,n} \\ a_{2,1} & a_{2,2} & \dots & a_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1} & a_{n,2} & \dots & a_{n,n} \end{bmatrix}$$

For Cholesky decomposition, assume matrix A has the form:

$$A = LL^T \quad \begin{bmatrix} a_{1,1} & a_{1,2} & \dots & a_{1,n} \\ a_{2,1} & a_{2,2} & \dots & a_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1} & a_{n,2} & \dots & a_{n,n} \end{bmatrix} = \begin{bmatrix} l_{1,1} & 0 & \dots & 0 \\ l_{2,1} & l_{2,2} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ l_{n,1} & l_{n,2} & \dots & l_{n,n} \end{bmatrix} \begin{bmatrix} l_{1,1}^T & l_{1,2}^T & \dots & l_{1,n}^T \\ 0 & l_{2,2}^T & \dots & l_{2,n}^T \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & l_{n,n}^T \end{bmatrix}$$

$$X \sim \mathcal{N}(\mu, \Sigma) \quad \Sigma = E[(X - \bar{\mu})(X - \bar{\mu})^T] = \begin{bmatrix} \sigma_{1,1} & \sigma_{1,2} & \dots & \sigma_{1,d} \\ \sigma_{2,1} & \sigma_{2,2} & \dots & \sigma_{2,d} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{d,1} & \sigma_{d,2} & \dots & \sigma_{d,d} \end{bmatrix}$$

$$\sigma_{i,j} = E[(\bar{x}_i - \bar{\mu}_i)(\bar{x}_j - \bar{\mu}_j)]$$

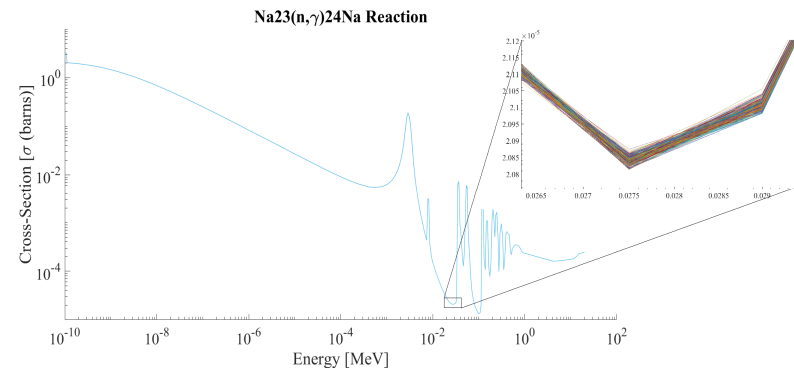
$$\Sigma = LL^T \quad \bar{z} = (z_1, \dots, z_d)^T, \quad Z_i \sim \mathcal{N}(0, 1)$$

$$x = \mu + LZ$$

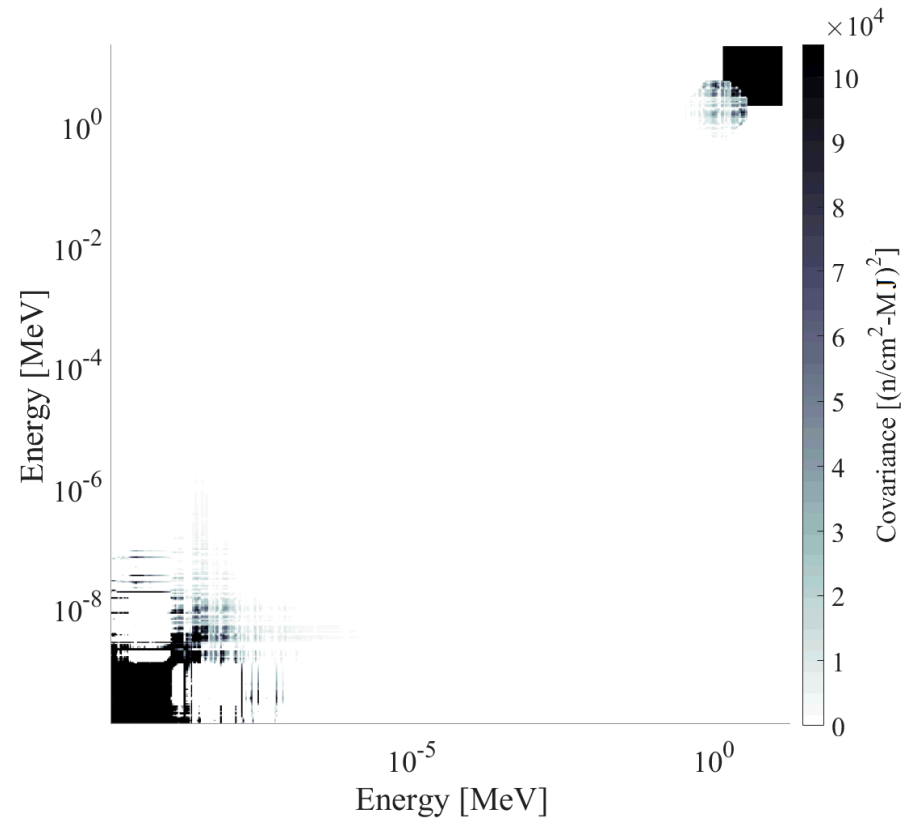
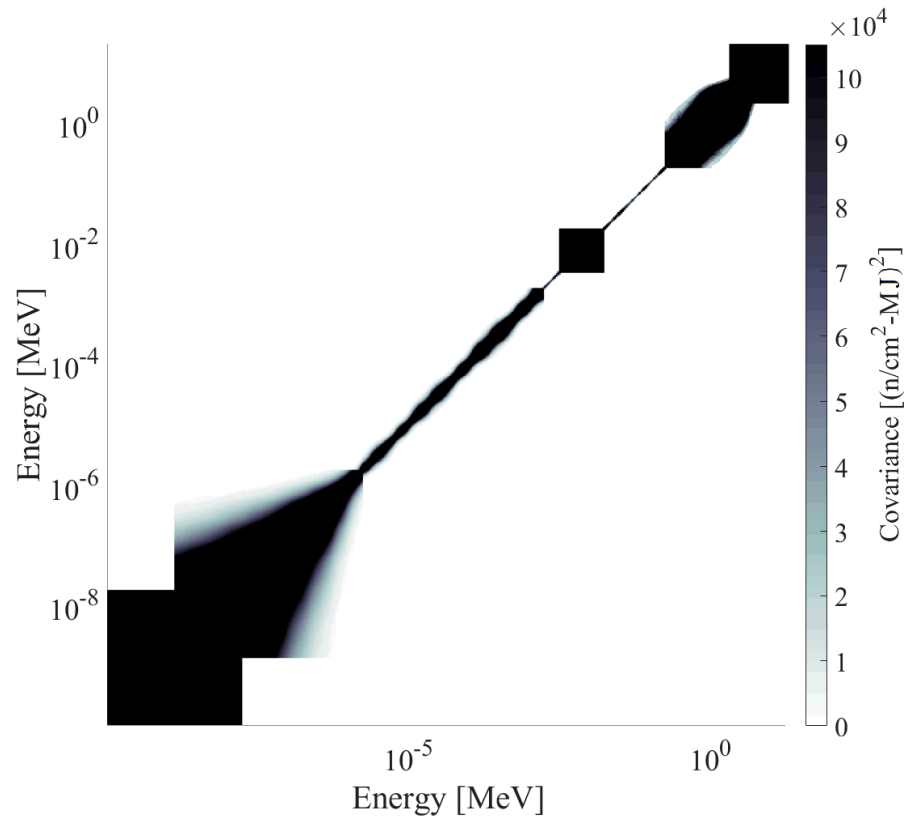
$$Z \sim \mathcal{N}(0, 1), \quad \Sigma(Z) = E[ZZ^T] = I$$

$$E[XX^T] = E[LZ(LZ)^T] = E[LZZ^T L^T]$$

$$\therefore E[XX^T] = LE[ZZ^T] = LL^T = \Sigma(X)$$

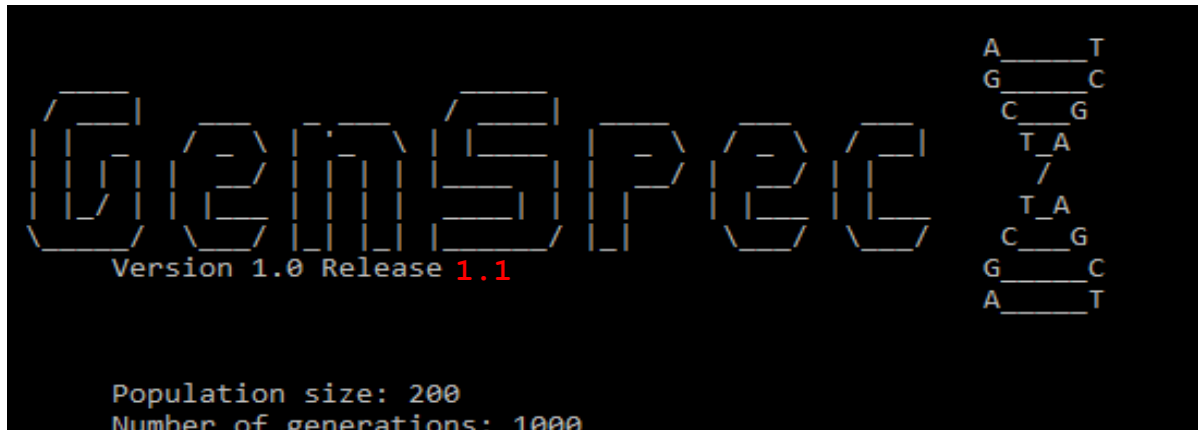
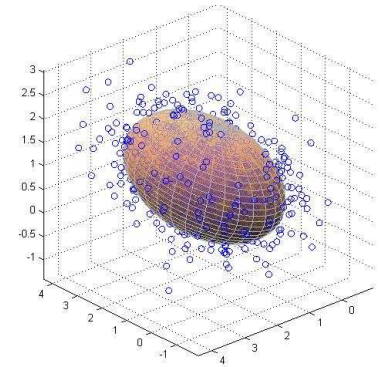
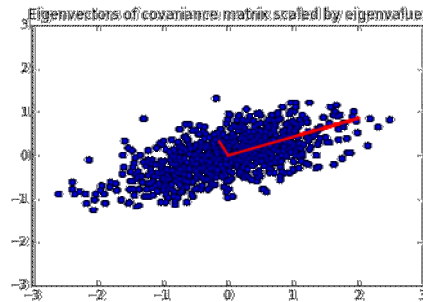
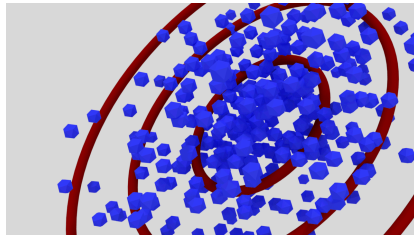


- What are the results?
 - Not bad, considering complexity...but we have a problem
 - “Don’t assume people are smart” & “The covariance *might* be made up”



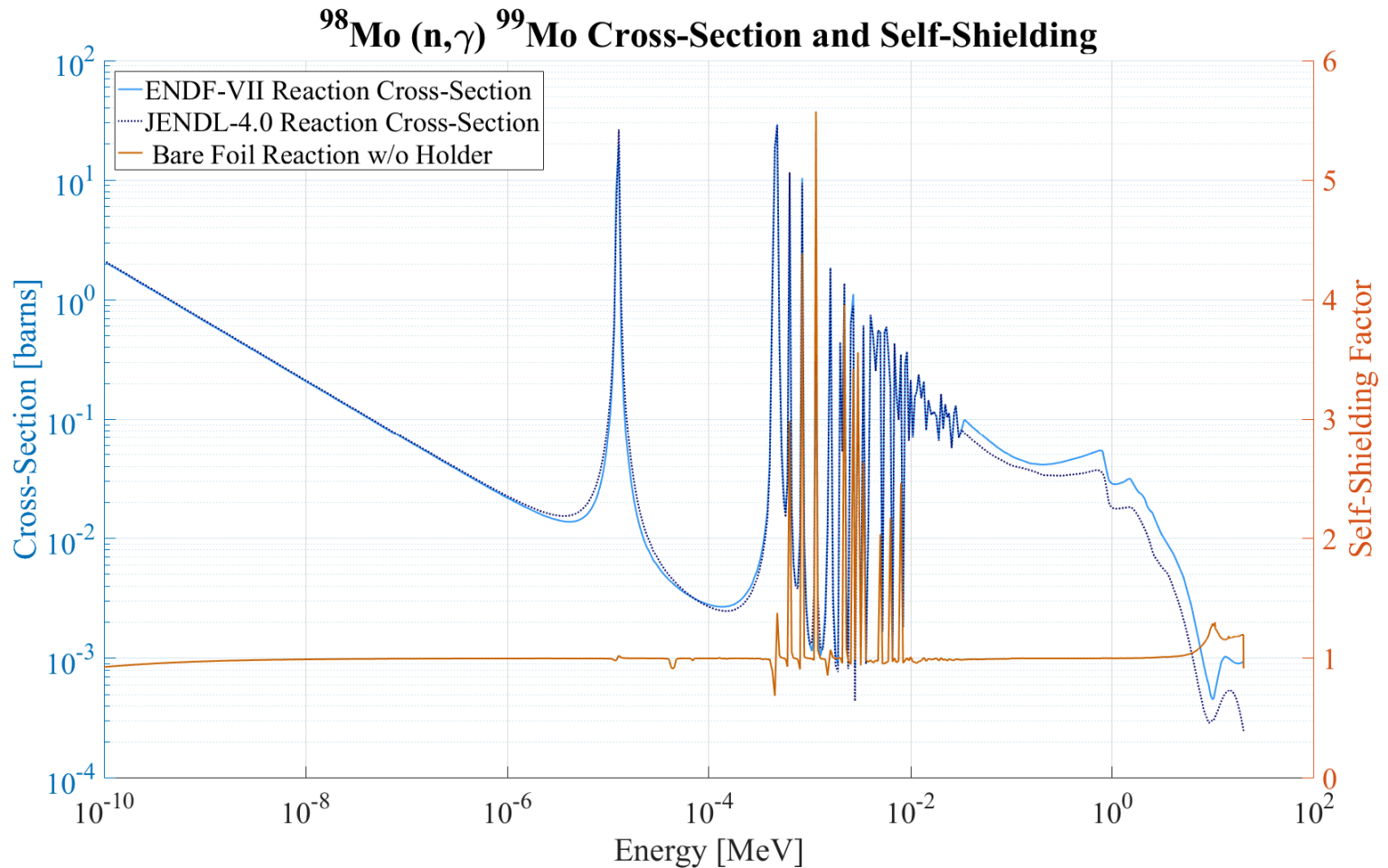
Current Status

- Just finished graduate M.S. degree at Texas A&M University
- GenSpec requires a re-write and update prior to a possible release, which means I need to redo the UQ process again
- Developing UQ visualization with Blender



Current Status

- Self-Shielding results for reactor testing results



Future Work

- A Ph.D. has been mentioned more than once
 - Development of an experimental class series
 - Focus on work with ACRR, and Neutron Activation Analysis
 - Test Run this class on unknowing grad students at TAMU (or UNM)
- Continued work with GenSpec®
 - Probably will work on this for a long time (i.e. entire career)
 - UUR Release
 - Return to work on experiments and hands-on activities



- Keep Traveling

Questions?