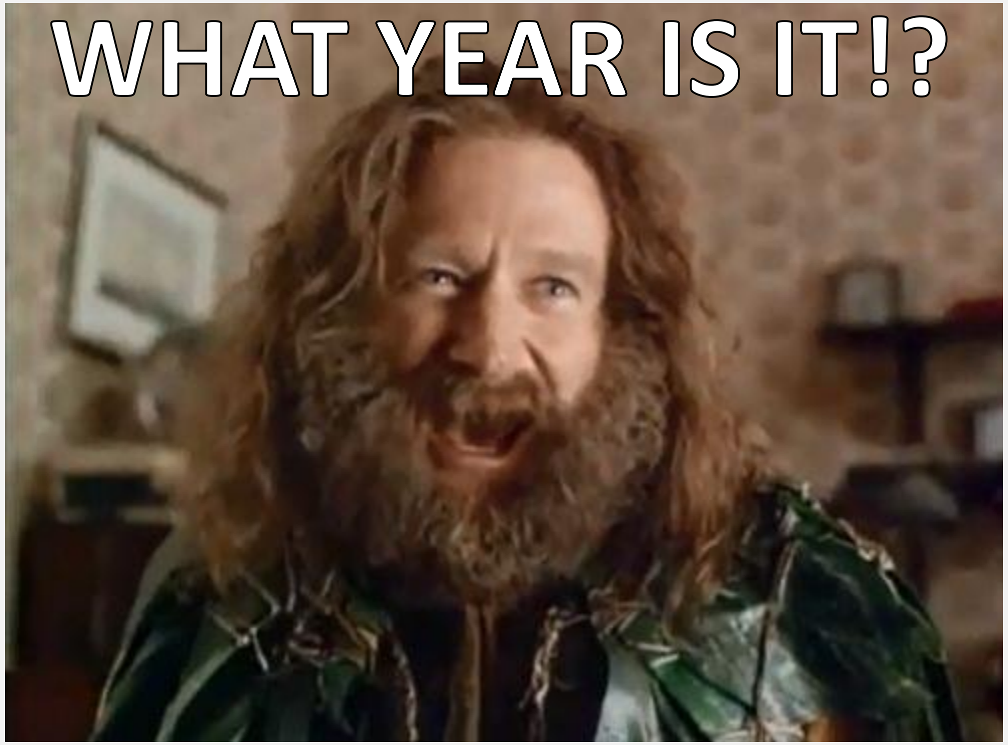
PHYS 6751: Graduate Nuclear & Particle Lab

- Introduction
- Radiation Safety
- Data Analysis Basics

Course Overview

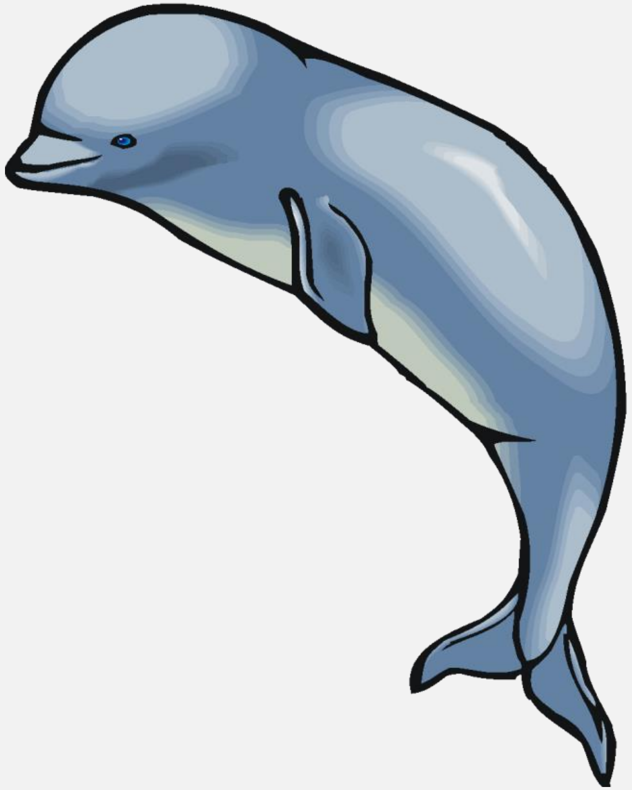
Basic Info

- Instructor:
  - Me (Zach Meisel)
  - Office 204 Edwards Accelerator Laboratory
  - meisel@ohio.edu
- Class Time & Location:
  - Tuesday & Thursday, 2:00-3:50pm
  - 208 & 101 Edwards Lab
- Office Hours:
  - Wednesday, Time TBD
- Pre-requisites: None



Purpose of this class

- Hands-on experience with equipment
- Use of contemporary open-source software
- Practice presenting scientific material
- Practice working in a team

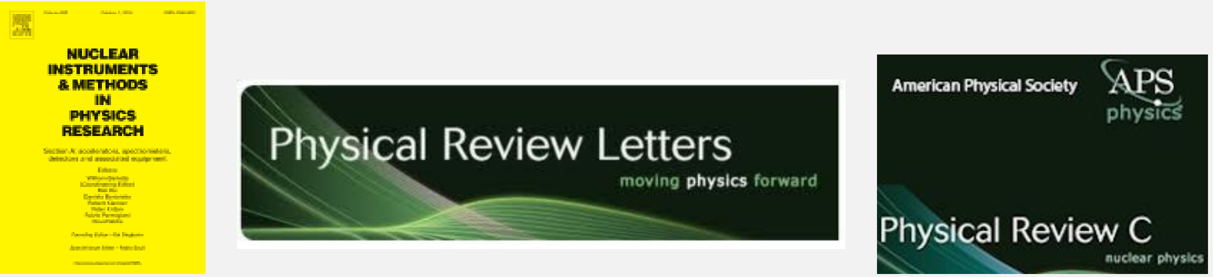


The course is based on performing 4 experiments

1. Foil thickness determination via α-spectroscopy
2. Measurement of the ^{197}Au(n,γ) cross-section
3. Characterization of a foil via Rutherford scattering
4. Determination of a neutron long-counter efficiency

Stuff you will be graded on

- Pre-lab run plans / preparatory notes
  - Clear plan of what to do & how to do it, i.e. including calculations & estimates
- Lab notebooks
  - Clear notes on what was done & why, what was observed
- Publication-style lab reports
  - Style depends on experiment



- End of semester presentation
  - 10min talk on one of the experiments (assigned)
- Participation

Radiation Safety

Safety

- Close-toed shoes required
- Hazards:
  - Tripping (it’s an active lab, watch your step)
  - Pinch (esp. vacuum pumps)
  - Electrocution (high voltage)
  - Radiation (sources & prompt radiation)

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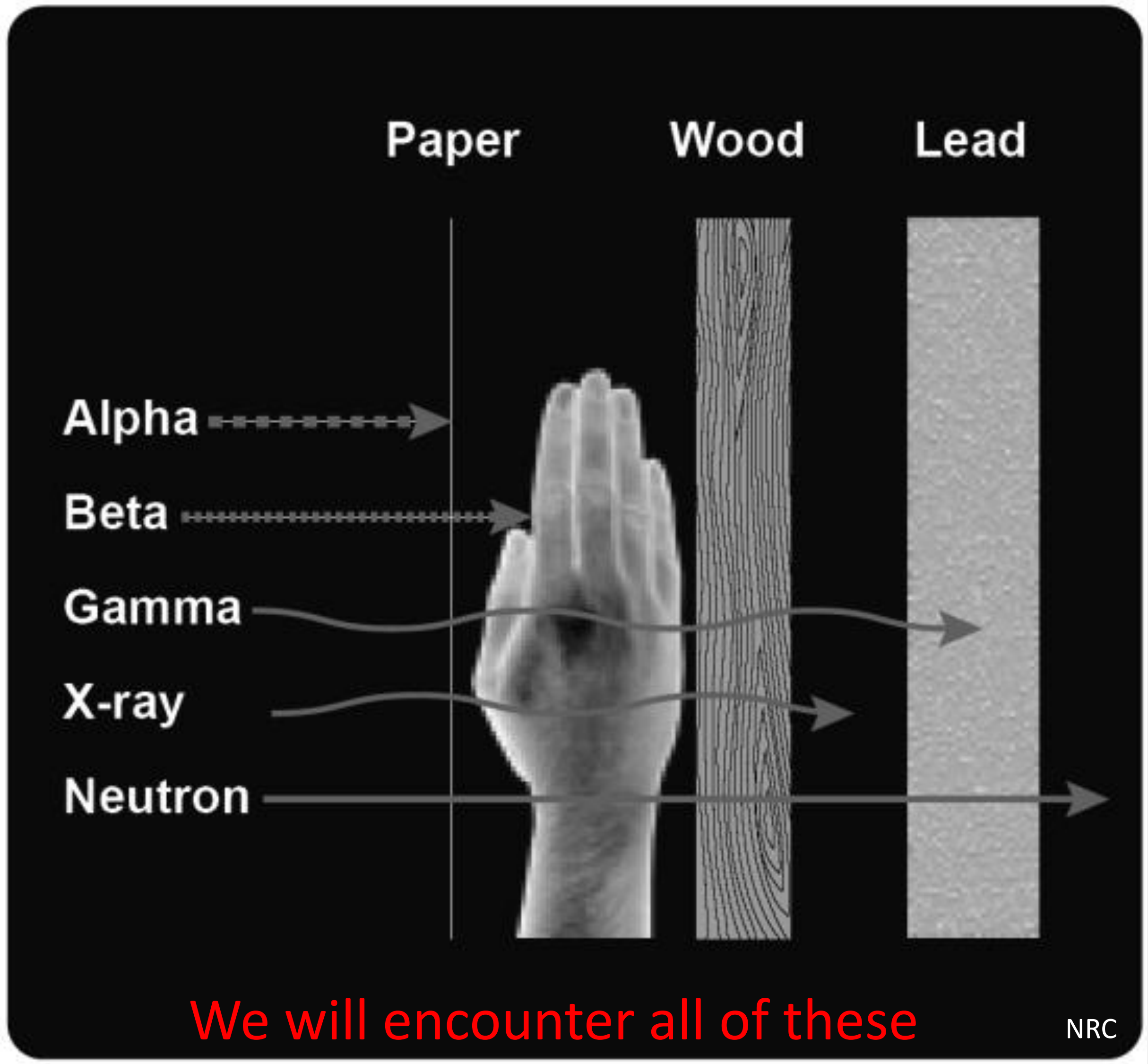
Radiation Safety: Types of *Ionizing* Radiation

Why do we have to worry about α-radiation if it stops in our skin?



We will encounter all of these

NRC

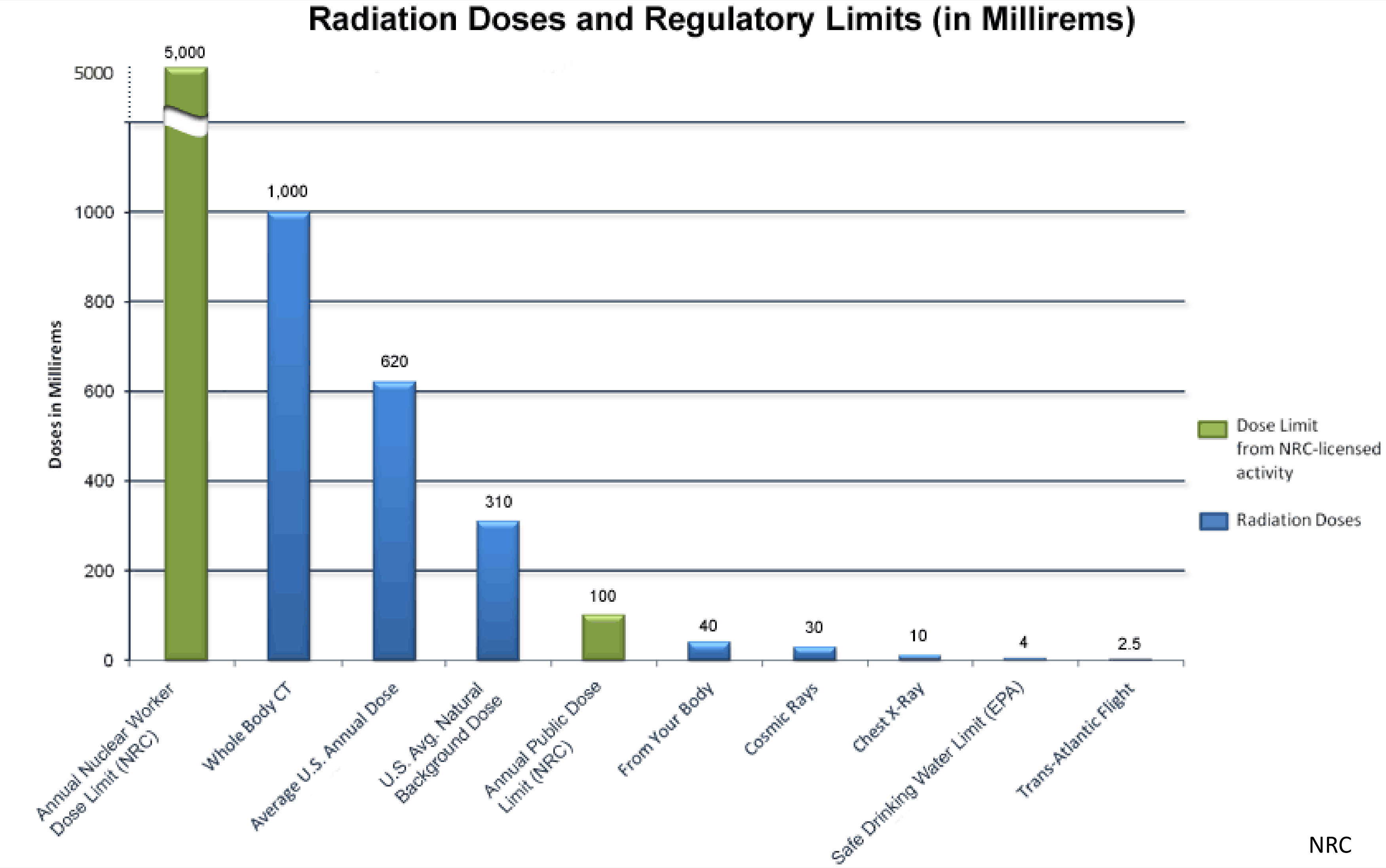
What are sources of each type of radiation?

Radiation Safety: Activity vs Dose

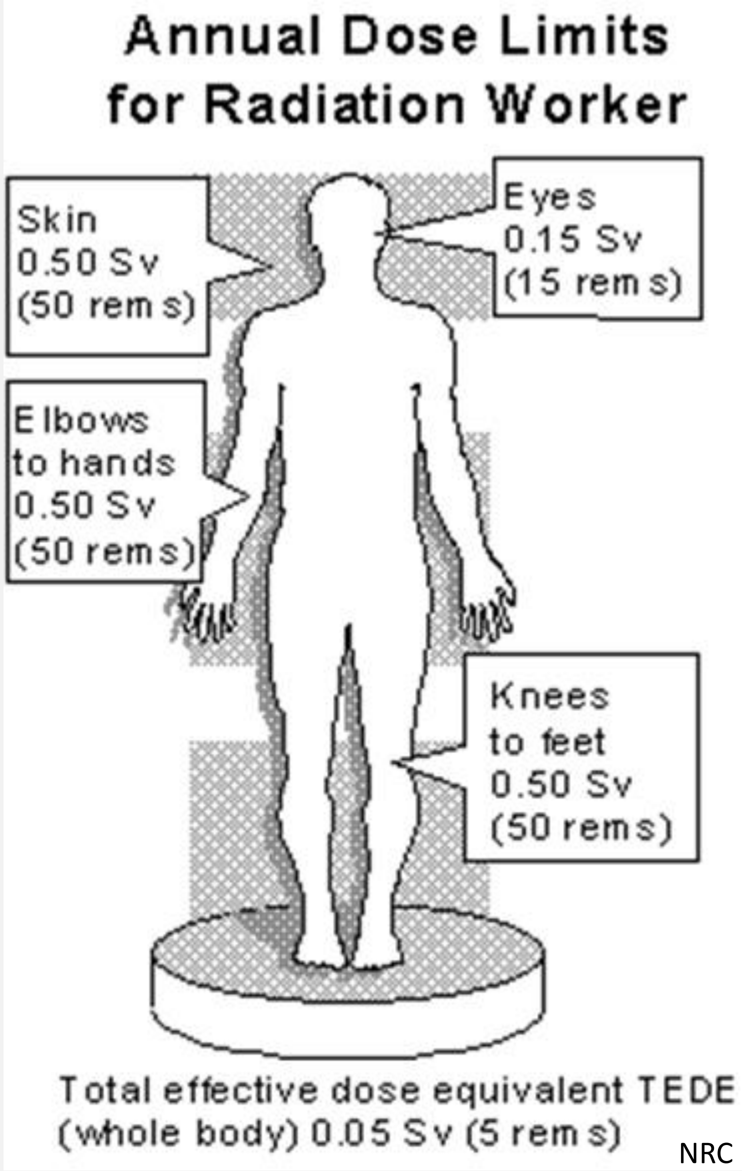
- Activity: Decays per unit time
  - Units: Curie (USA), Bequerel (everywhere else)
  - 1 Curie (Ci) = $2.22\text{x}10^{12}$ disintegrations per minute
  - 1 Bequerel (Bq) = 1 disintegration per second
  - 1 Ci is a high activity!

- Equivalent Dose: Radiation absorbed by tissue, accounting for its damage
  - Units: Roentgen Equivalent Man (USA), Sievert (everywhere else)
  - 1 Sievert (Sv) = 100 Roentgen equivalent man (Rem)
  - 1 Rem is a large dose!

Radiation Safety: Dose Limits



NRC



NRC

Radiation Safety: We will follow the ALARA principle

- ALARA: **A**s **L**ow **A**s **R**easonably **A**chievable
- Minimize dose by use of time, distance, & shielding
  - Minimize time near sources of radioactivity
  - Maximize distance from sources of radioactivity
  - Shield yourself from radioactivity (*use the proper shielding)
    - Beta: plexiglass
    - Gamma: lead, steel
    - Neutron: concrete, water
- Other safety precautions
  - No eating, drinking, applying make-up in the lab
  - Wear gloves when handling sources
  - Wash your hands when you're done working in the lab

Why is different shielding appropriate for different types of radiation?

IAEA

Data Analysis

Basics

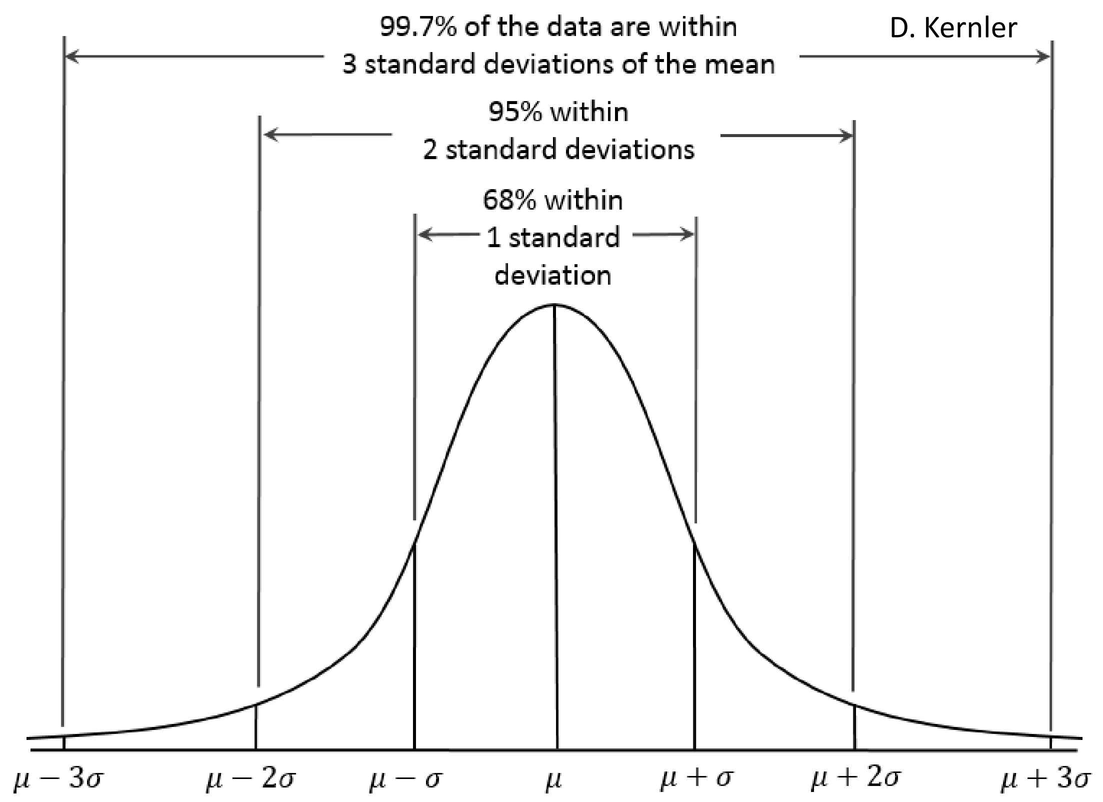
- In a nutshell, low energy nuclear physics data analysis comprises of:
  - Counting what you measured
  - Calibrating your measurement technique
  - Making cuts on and corrections to your data
    - E.g. calibrations, background subtractions
  - Fitting what you measured
    - *Often inferior to directly evaluating the data in a statistical way, e.g. finding peak centroids, peak widths, and background levels
- Analysis tools
  - Excel ...could use it for our data, since it's simple, but please don't!
  - Gnuplot ...good for simple, quick plotting & fitting
  - ROOT ...the standard for nuclear physics analyses, highly flexible, C++ or Python, many built-in tools (including graphical tools), graphical interface available. Please use this! (will go over basics next lecture)

The Normal Distribution, or ~~*Innocent*~~ *Gaussian until proven guilty*

- According to the Central Limit Theorem, averages of random variables independently drawn from independent distributions will converge to the Normal (a.k.a. Gaussian) distribution, so long as the distributions have a finite variance (a.k.a. spread).
- Similarly, the product of normal distributions is a normal distribution
- Therefore, we frequently fit peaks in our data (e.g. α energy in an Si detector) with Gaussians
  - This is a good idea to identify things such as two overlapping peaks or an uneven background
  - However, for single peaks, the statistical mean & variance are preferred to the mean & variance from a fit; i.e. **counting is better than fitting**, when possible

Relevant information from a Gaussian peak

- Mean: $\bar{x} \equiv \langle x \rangle = \frac{1}{N}\sum_{i=1}^{N} x_i$
- Variance: $\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \langle x \rangle)^2 = \frac{1}{N}\sum_{i=1}^{N} {x_i}^2 - \langle x \rangle^2 = \langle x^2 \rangle - \langle x \rangle^2$
- Standard deviation: σ ("GetRMS" in ROOT returns this!)
- Error in the mean: $\delta\langle x \rangle = \frac{\sigma}{\sqrt{N}}$
- Probability:
  - When specifying #σ, where # is some number, we're specifying the likelihood a given measurement would fall within that distance from the mean
  - Typically, "uncertainty" refers to the 1σ value
- Width:
  - Generally means the Full-Width at Half-Maximum
  - FWHM=2.35σ



Background & the ‘critical limit’, or *To peak or not to peak?*

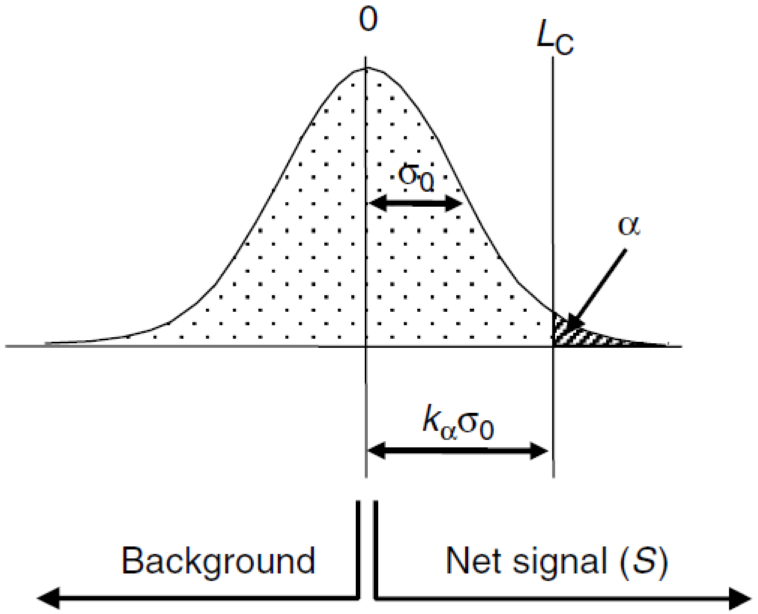


Figure 5.9 Definition of critical limit (the vertical axis represents the frequency of observing a particular count)

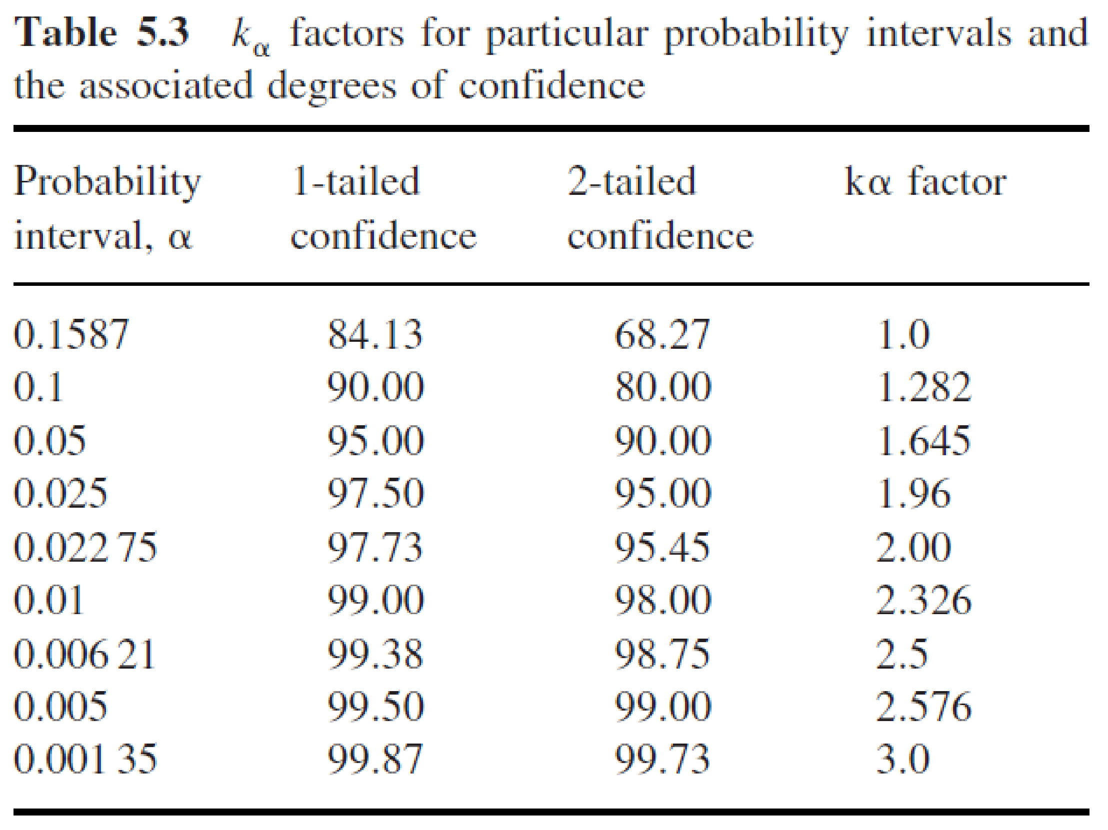
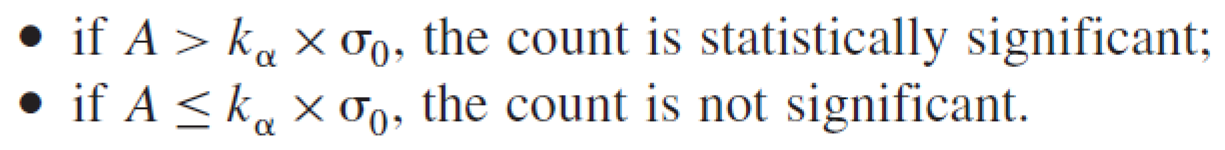
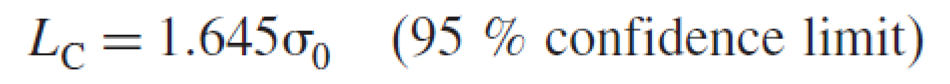


Table 5.3 k_α factors for particular probability intervals and the associated degrees of confidence

Probability interval, α	1-tailed confidence	2-tailed confidence	kα factor
0.1587	84.13	68.27	1.0
0.1	90.00	80.00	1.282
0.05	95.00	90.00	1.645
0.025	97.50	95.00	1.96
0.022 75	97.73	95.45	2.00
0.01	99.00	98.00	2.326
0.006 21	99.38	98.75	2.5
0.005	99.50	99.00	2.576
0.001 35	99.87	99.73	3.0



- if $A > k_\alpha \times \sigma_0$, the count is statistically significant;
- if $A \leq k_\alpha \times \sigma_0$, the count is not significant.



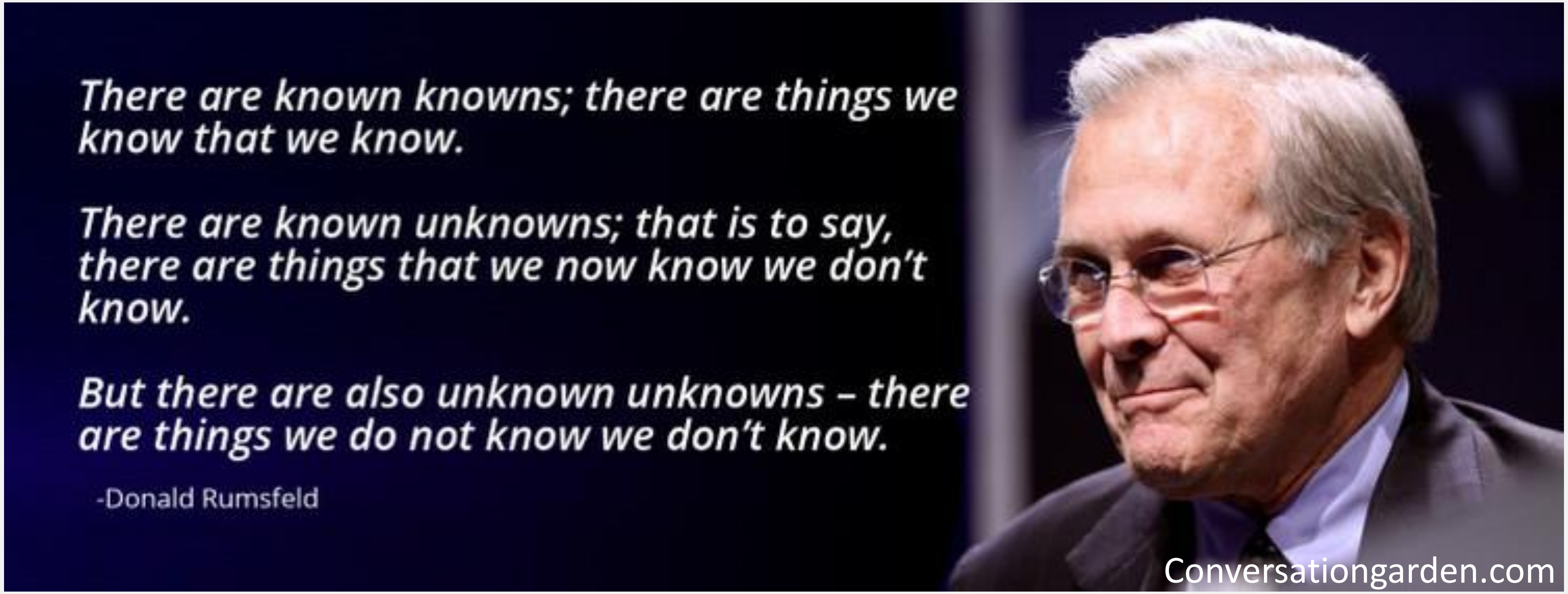
$$L_C = 1.645\sigma_0 \quad (95\ \%\ \text{confidence limit})$$

See Chapter 5 of Gordon Gilmore’s “Practical Gamma-ray Spectrometry”

Uncertainties in one (ugly) slide

- Statistical
  - Scatter based on finite measurement sample. Well defined, e.g. $\delta N = \sqrt{N}$, so $\frac{\delta N}{N} = \frac{1}{\sqrt{N}}$
  - Add in quadrature, e.g. $\delta f(x, y) = \sqrt{\delta x^2 + \delta y^2}$ (Independent case. Need covariance otherwise)
- Systematic
  - May be identified…
    - e.g: Measure known quantity simultaneously
    - e.g.: Repeatability (quoted or measured) of measurement device
  - or inferred
    - e.g.: Account for extra scatter in data
    - e.g.: Account for bias in data causing variation from known analytic relationship
  - Can verge on the philosophical and is often open to reasonable disagreement
  - Typically add linearly ….unless "statistically distributed" (see comment on philosophy)
- Pro-tips:
  - Identify your limiting uncertainty before setting out to perform a measurement
  - The reduced-chi-square of a fit gives an idea if uncertainties are over- or underestimated (should be ≈ 1)
    - $\chi^2_{red} = \frac{1}{N_{data} - N_{param}} \sum_{i=1}^{N} \left(\frac{y_i - f(x)}{\delta y_i} \right)^2$, where N_{data} =# of data points, N_{param} = # parameters of a function $f(x)$, $f(x)$ is the function being compared to (likely via a fit) to data described by x, y, and δy_i is the uncertainty of the data point given by y_i
    - However, the reduced chi-square may also be telling you your analytic model is wrong!
    - $\chi^2_{red} \gg 1$ means uncertainties are underestimated or poor fit (too few parameters, likely). $\chi^2_{red} \ll 1$ means the opposite.

Comments on uncertainty assignment



There are known knowns; there are things we know that we know.

There are known unknowns; that is to say, there are things that we now know we don't know.

But there are also unknown unknowns – there are things we do not know we don't know.

-Donald Rumsfeld

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- Do your best and be honest about how well you actually know things. i.e. carefully identify and describe 'known unknowns'
- …not much you can do about 'unknown unknowns'. For these we rely on the corrective nature of science.
- "There are no wrong answers, only wrong error bars" -wise old scientist

Assignment

- Read the article on scientific writing from Scientific American
- Read the discussion on the statistics of counting from Gordon Gilmore
- Glance at the propagation of uncertainty from John Taylor

*All readings are on the course website & Blackboard