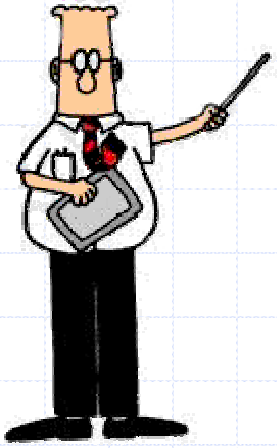
Model-Assisted POD

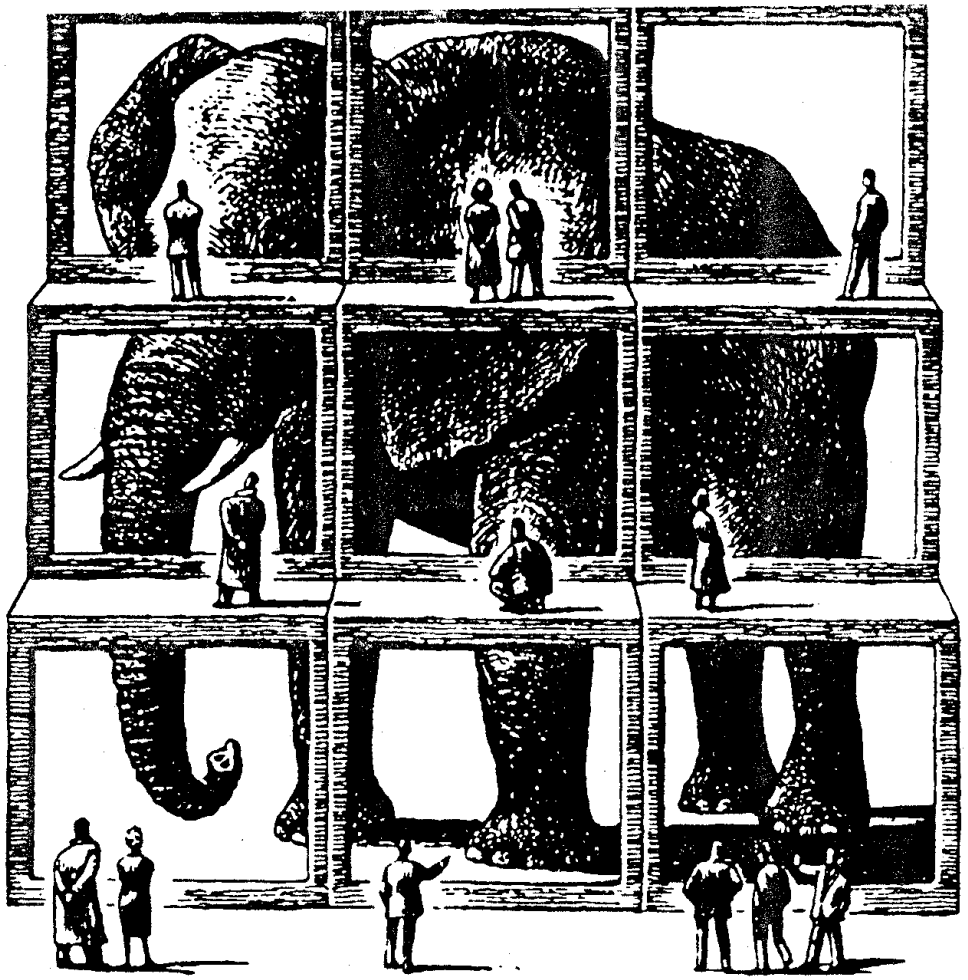
TESI's perspective



Chuck Annis

Charles Annis, P.E.
Statistical Engineering

“Model-Assisted” depends on what the definition of “is” is.

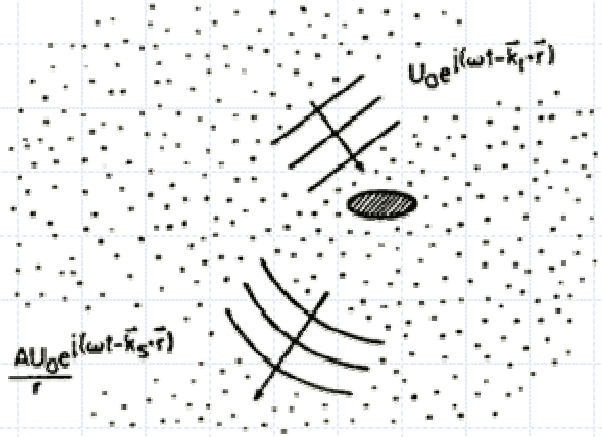


Christophe Vorlet

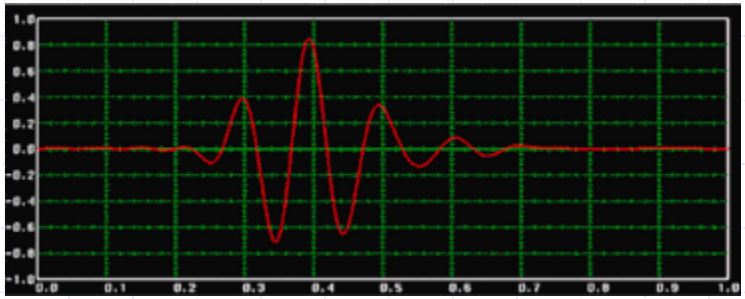
Charles Annis, P.E.
Statistical Engineering

“Model-Assisted” depends on what the definition of “is” is.

e.g.: Attenuation model is global; it does not attempt to model interactions with individual microstructural constituents.



Geometry of theoretical scattering calculation



$$A = A_0 e^{-\alpha z}$$

where A is the attenuated amplitude at location z, A_0 is the original amplitude, and α is attenuation coefficient.

Reference:
http://www.ndt-ed.org/EducationResources/CommunityCollege/Ultrasonics/CalibrationMeth/thompsongray.htm

Charles Annis, P.E.
Statistical Engineering

TESI uses global models too:

Signal strength depends on target size, morphology & location, part geometry, probe, scan-plan ...

$$\hat{a}_i = \beta_0 + \beta_1 a_i + \beta_2 \%N + \beta_3 e^{-\alpha Z_i} + \varepsilon_i$$

a_i	$\%N$	$exp(Z_i)$
$log(a_i)$	$log(\%N)$	Z_i
$1/a_i$	$1/\%N$	$1/Z_i$

Stochastic component

Physical theory can *suggest* the form of the mathematical model.

Charles Annis, P.E.
Statistical Engineering

Heuristics are an integral constituent of Model Building

e.g: Signal-to-Noise Ratio

$$\frac{S}{N} = \sqrt{\frac{16}{\rho\, v_{metal}\; w_x w_y \Delta t}}\; \frac{A_{flaw}(f_0)}{FOM(f_0)}$$

Flaw scattering Amplitude at center frequency

Sonic velocity in metal

Lateral beam widths at flaw depth

Pulse duration

Noise "Figure-of-Merit" at center frequency

Note: TESI does not use this formulation

Reference:
http://www.ndt-ed.org/EducationResources/CommunityCollege/Ultrasonics/Physics/signaltonoise.htm

Charles Annis, P.E.
Statistical Engineering

“Model-Assisted”

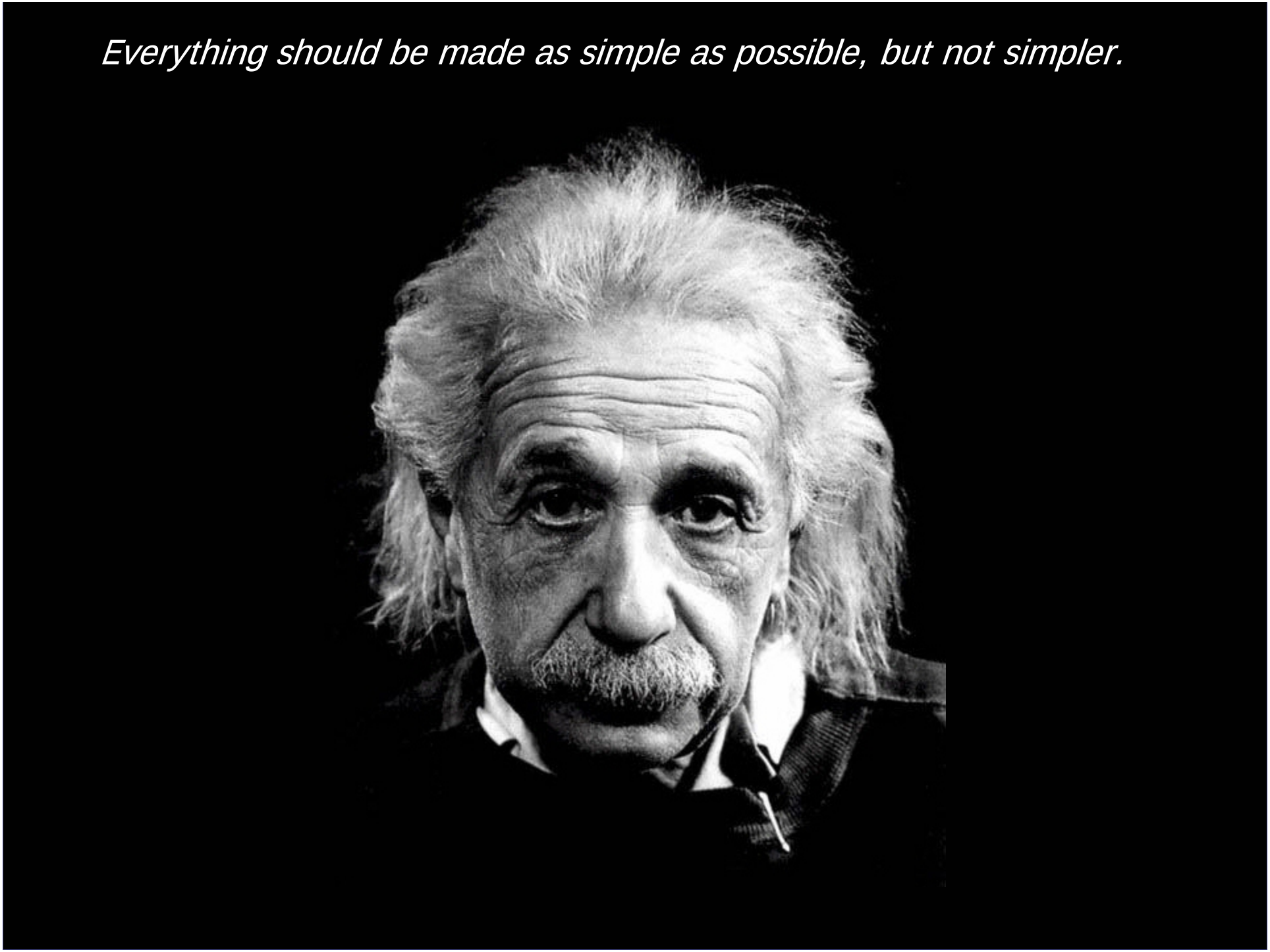
... depends on what you want to model

- complete waveform or
- maximum amplitude at a location (voxel).

... then choose mathematical models of *appropriate* complexity to augment what can be inferred from the raw data alone.

Charles Annis, P.E.
Statistical Engineering

Everything should be made as simple as possible, but not simpler.



UDRI/TESI Plan for UT/POD Reliability Testing

- Define the Goal.
- Work backwards from the goal to where we are.
- Follow the breadcrumbs to lay out a roadmap.

Charles Annis, P.E.
Statistical Engineering

How to get there from here:

Goal: POD for the TESI System

- We need a quantitative method for comparing NDE systems.
- This will allow us to say that the TESI system is better than (a comparative system) and by how much.

Charles Annis, P.E.
Statistical Engineering

Goal:

- Provide a quantitative measure of NDE effectiveness.
- "POD" is *part* of the answer.
  - POD is *not* a single number but depends on these factors:
  - Intrinsic – system capability
  - Extrinsic – target/noise characteristics
  - *Combined – intrinsic/extrinsic synergism*

POD can be generalized:

- Probability of detection is a *function*.
- This function can be evaluated at interesting conditions.
- System comparisons must consider more than a single number.
  - Car mileage *vs* acceleration
  - NDE sensitivity *vs* system throughput.

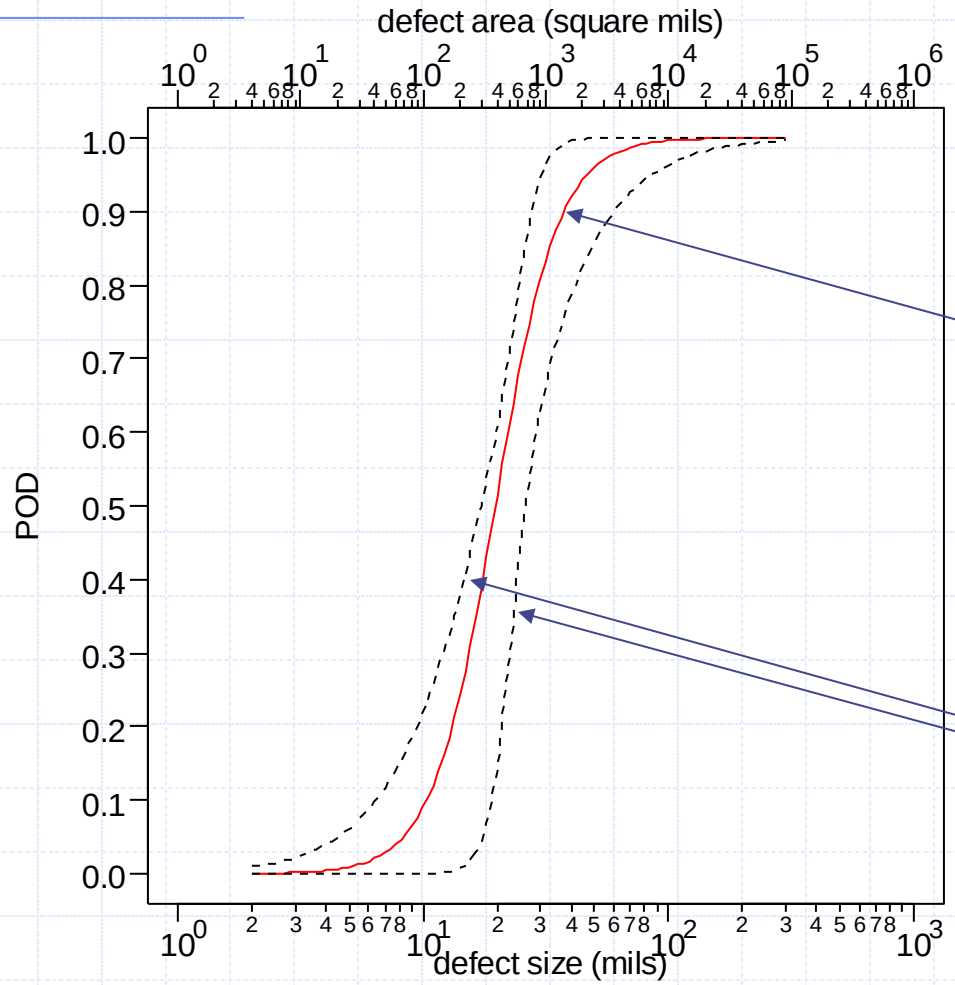
TESI goodness criteria

- Compare two systems' POD *functions* * (mathematical descriptions of capability)
  - Are they *meaningfully* different?
  - If so, which one is better?

* *The entire function everywhere, not just its value at one condition*

Charles Annis, P.E.
Statistical Engineering

Working backwards – Goal: POD function



This is what we want.

POD *function*

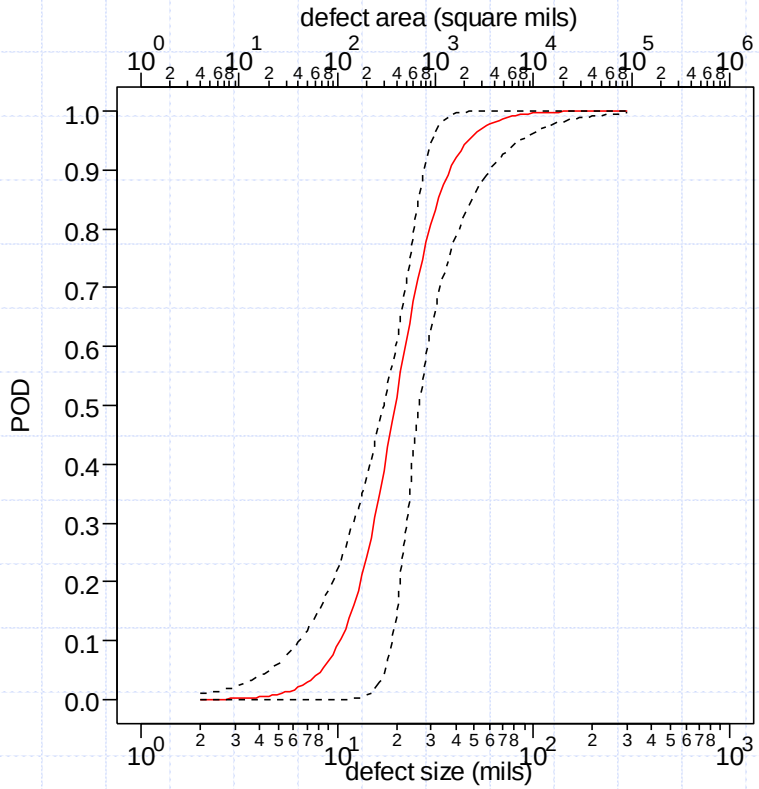
POD = f (target size, chemistry, shape, orientation, depth, entry surface curvature, probe characteristics, system settings, …)

Confidence bounds

(target size is only one of many variables)

Charles Annis, P.E.
Statistical Engineering

Working backwards –



This is what we want.

POD = f (target size, chemistry, shape, orientation, depth, entry surface curvature, probe characteristics, system settings, …)

This is what we need to get it

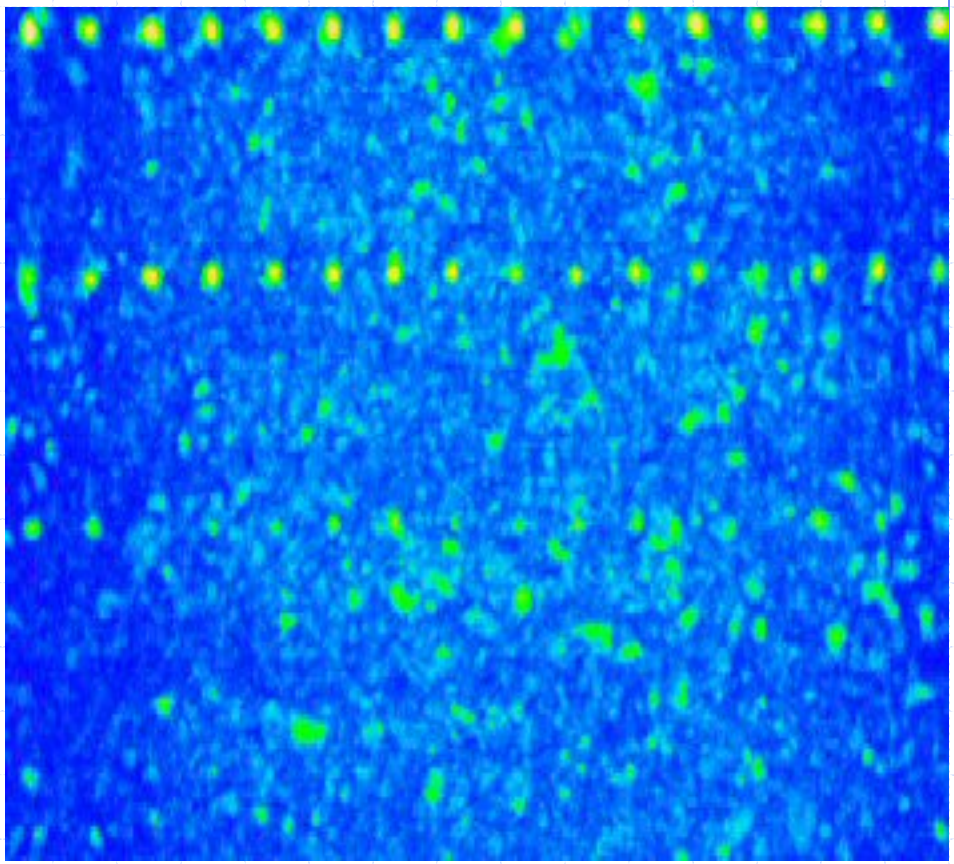
Charles Annis, P.E.
Statistical Engineering

Working backwards –

Descriptive function

POD = f (target size, chemistry, shape, orientation, depth, entry surface curvature, probe characteristics, system settings, ...)

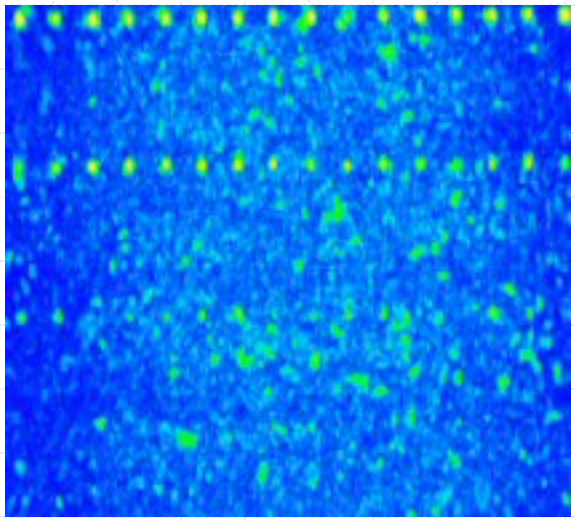
C-scan



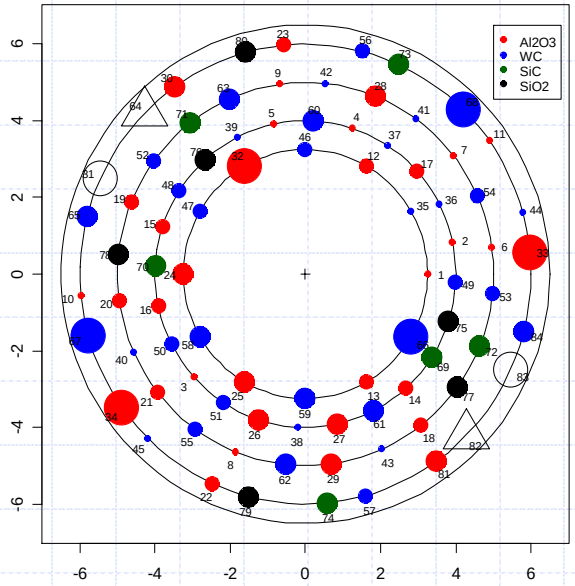
Charles Annis, P.E.
Statistical Engineering

Working backwards –

Optimized C-scan



TESI DOX specimens



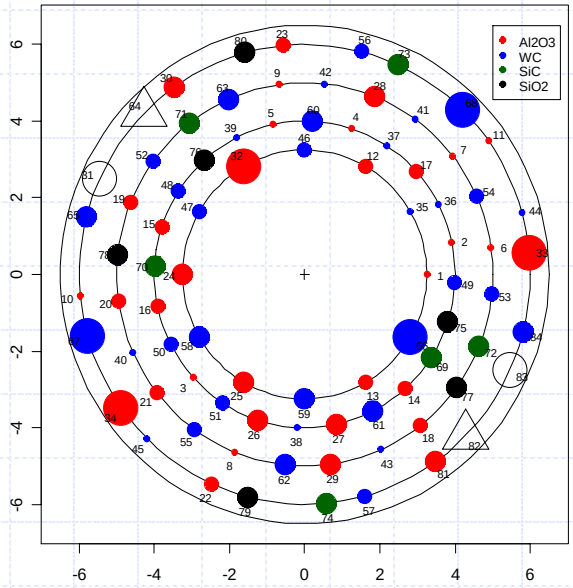
Selected variables:

target size, chemistry, depth, surface curvature, background noise, *and their interactions*

Charles Annis, P.E.
Statistical Engineering

Working backwards –

TESI DOX specimens

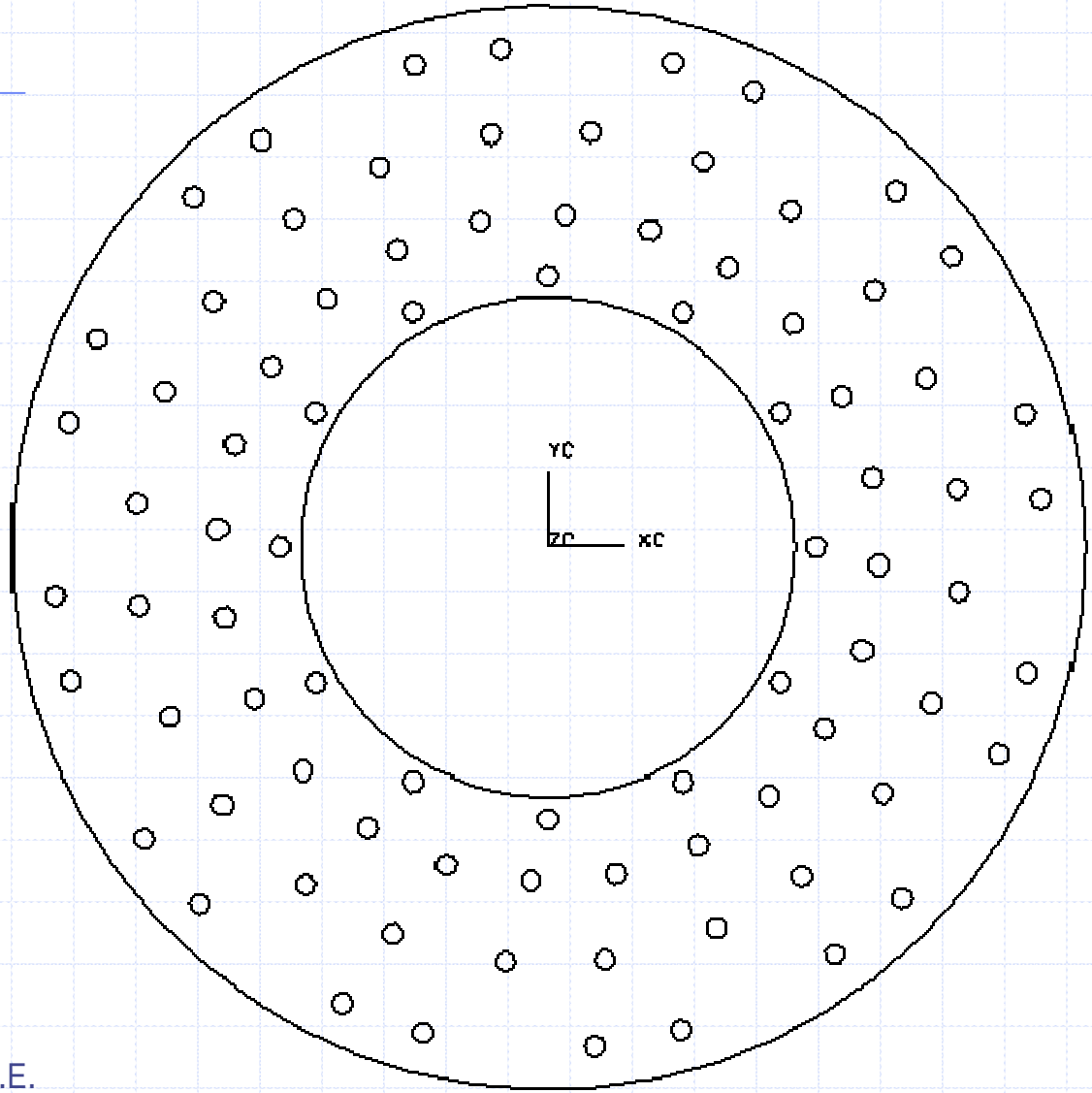


Selected variables:

1. size
2. chemistry
3. depth
4. surface curvature
5. background noise (low)
6. *interactions*

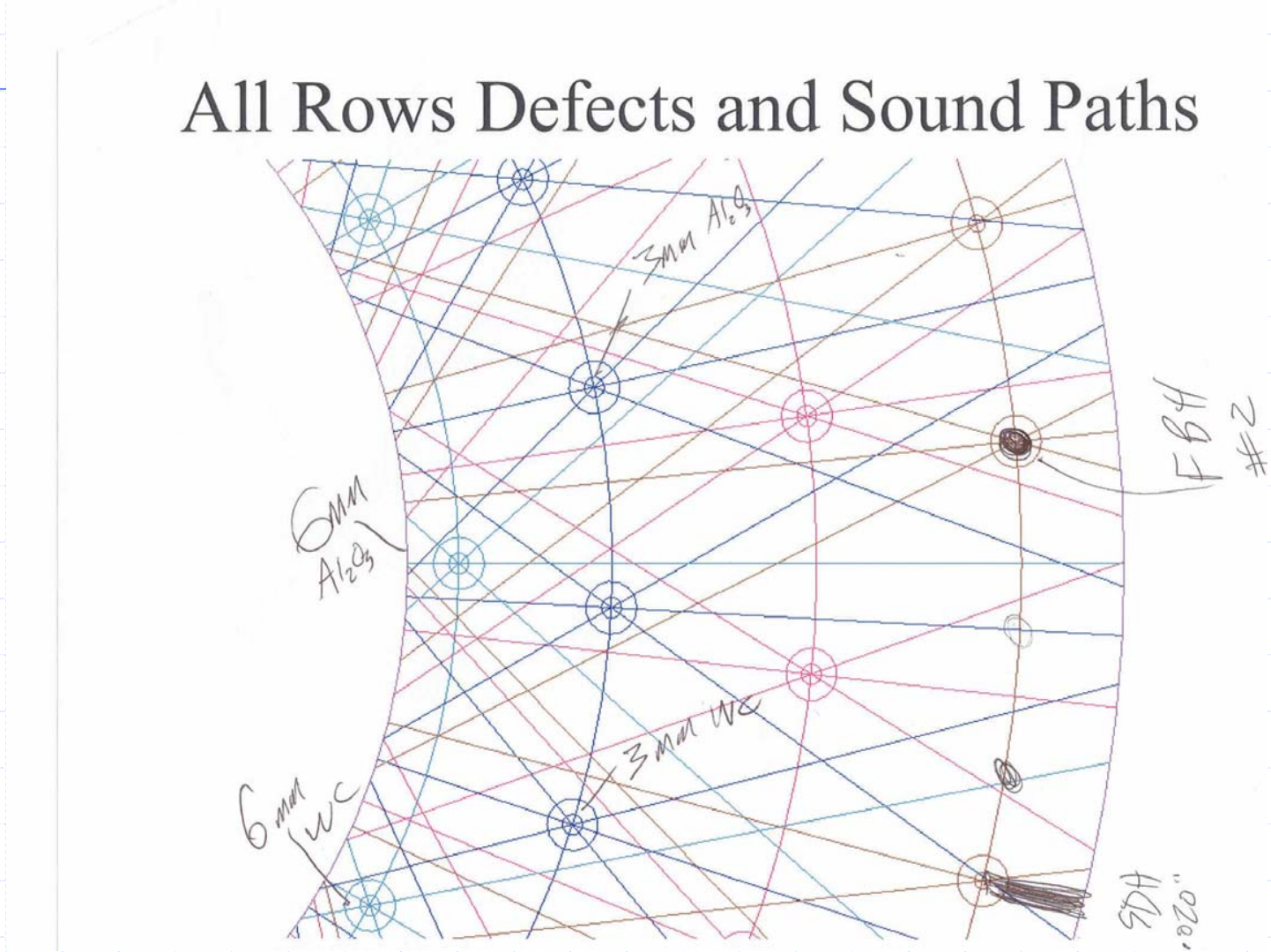
Charles Annis, P.E.
Statistical Engineering

UT Targets are strategically located



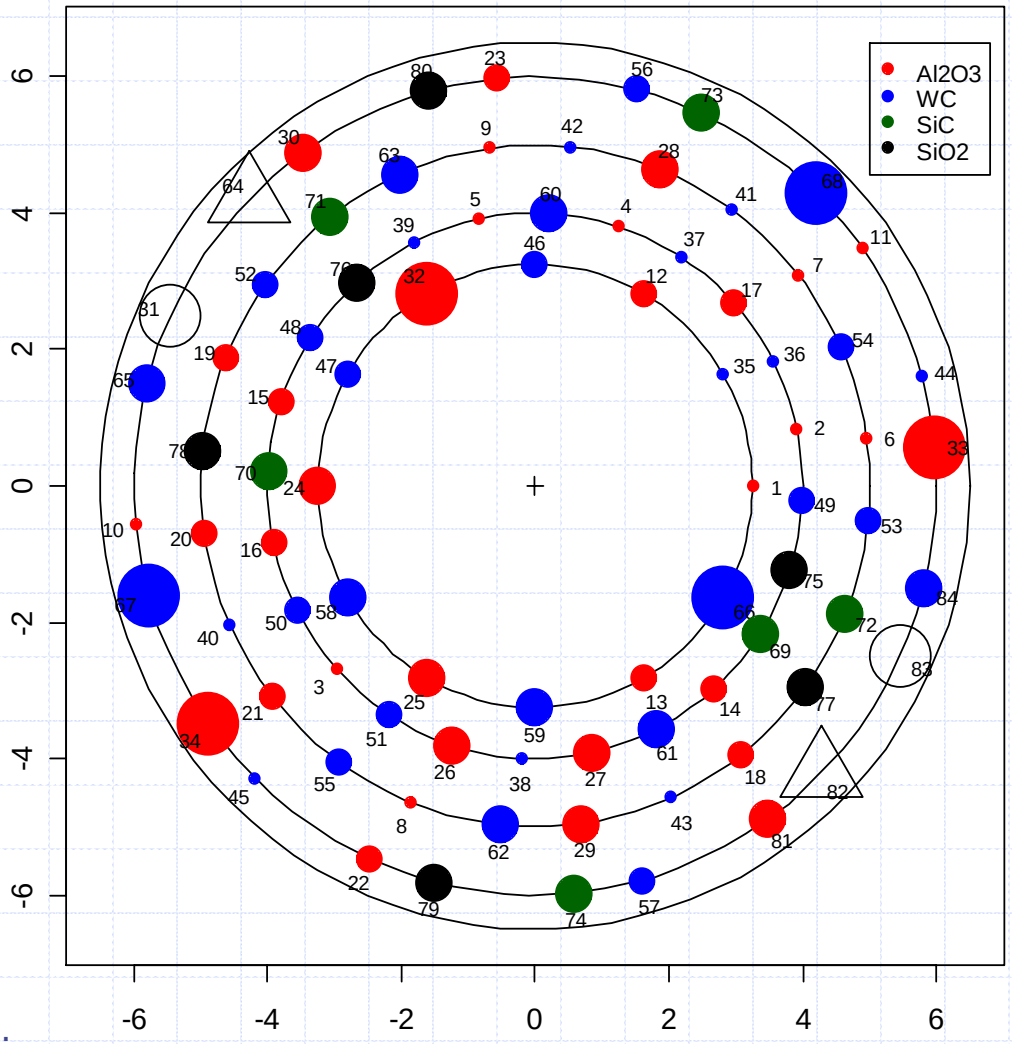
Charles Annis, P.E.
Statistical Engineering

Al Klassen's Ray-tracing



Charles Annis, P.E.
Statistical Engineering

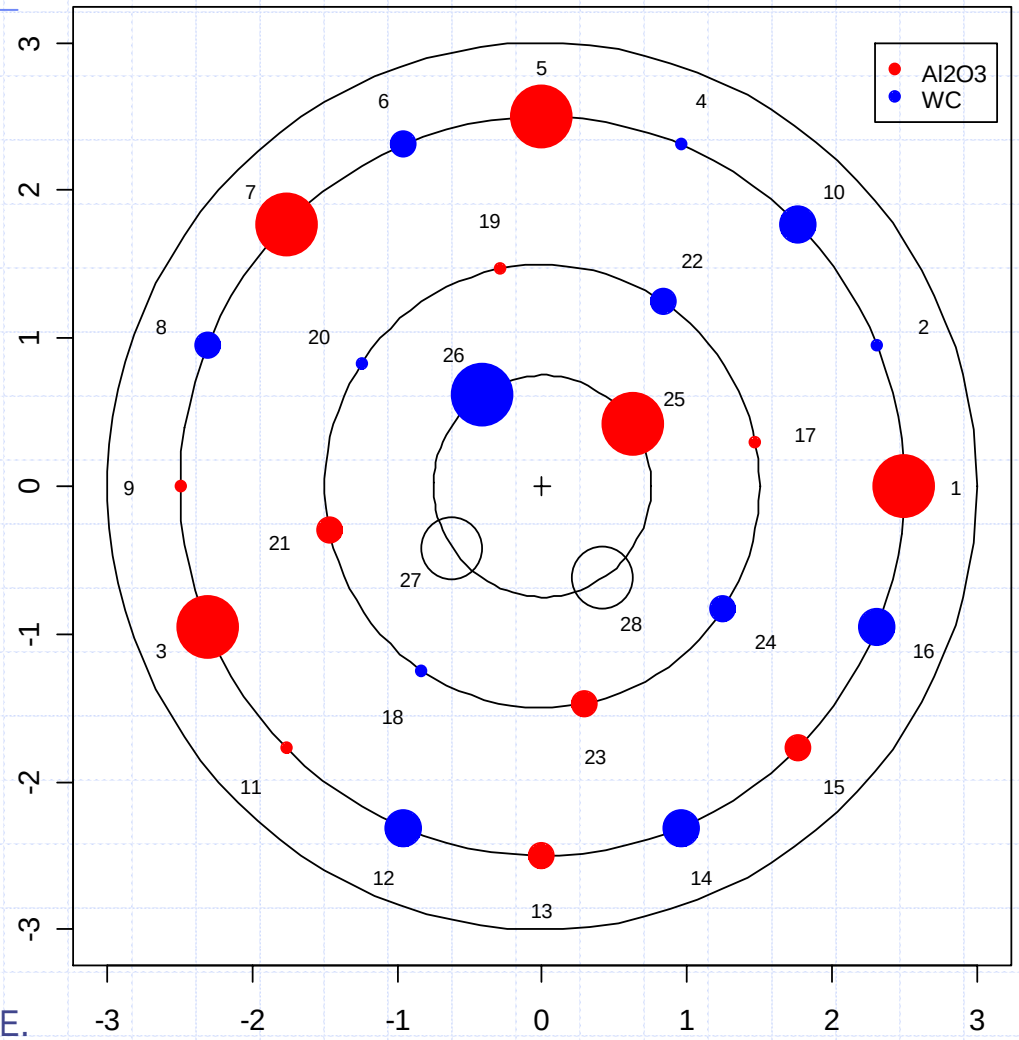
Designed Experiment – outer disk



Symbols are *NOT* to scale

Charles Annis, P.E.
Statistical Engineering

Designed Experiment - inner disk



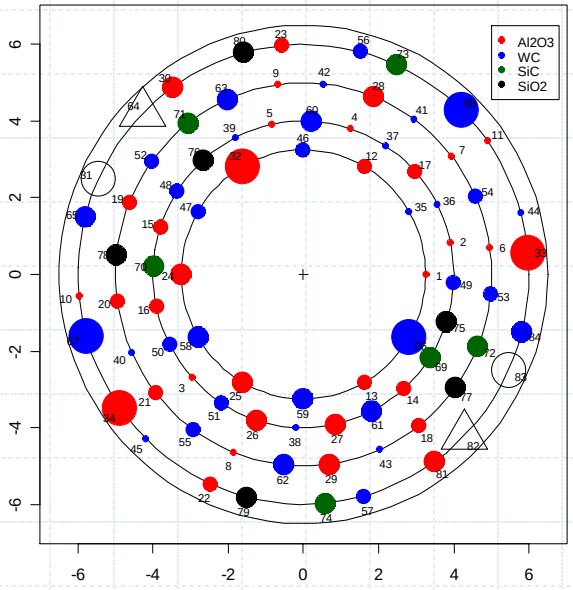
Symbols are *NOT* to scale

Charles Annis, P.E.
Statistical Engineering

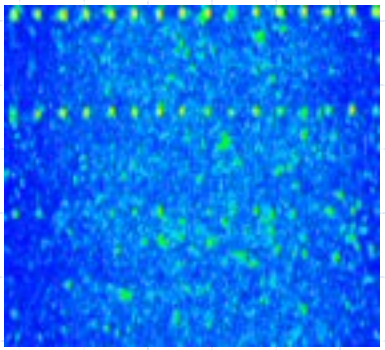
Review:
TESI Specimen to POD Function

1) Design TESI Specimens

2) Build them



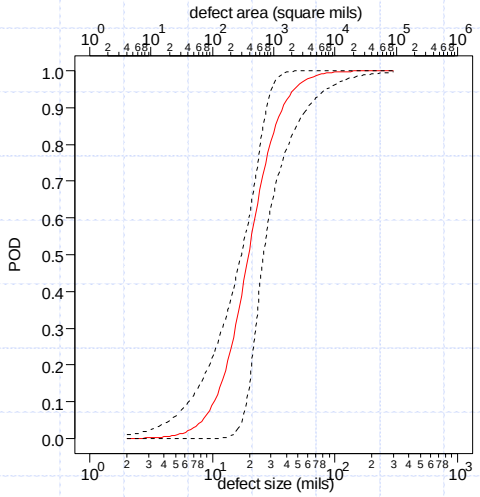
3) Exercise TESI system



4) Do the math and stats

$$\hat{a} = \beta_0 + g\left(\sum_{i=1}^{i=n} \beta_i f_i(x_i)\right)$$

5) Build the POD function



6) Use it to compare systems

Charles Annis, P.E.
Statistical Engineering

Things to Remember:

- *Any* system's performance must be *tested*.
- TESI is building a testing ensemble:
  - Hardware:
    - The 12½" dia and 6" dia DOX disks
    - The GEAE "DOE" test blocks
    - Other opportunities (e.g. SHA blocks – we hope)
  - Software:
    - Mathematical and statistical models based on interrogating constituents of the ensemble, statistically aggregating their responses, and leading to ...
    - POD models of system performance.

Charles Annis, P.E.
Statistical Engineering

“Model-Assisted” means ...

... using mathematical models *of appropriate complexity* to augment what can be inferred from the raw data alone.

... recognizing the intermediate goal:

- Using wave mechanics to describe the entire waveform?
- Or describing the maximum amplitude at a location (voxel)?

Charles Annis, P.E.
Statistical Engineering

Summary:

- TESI Goals in Model-Assisted POD are entirely consistent with those of the MAPODWG.
- We are pursuing models more statistical than physical, that nonetheless are firmly founded on physical principles.

Charles Annis, P.E.
Statistical Engineering