OEOSC Laser Damage Standard Development

NASA Contamination, Coatings Materials and Planetary Protection Workshop

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Why Revise The Specification ??????

- Existing standards for laser damage threshold measurement may not produce accurate, repeatable measurements
- Procedure is open to interpretation and these interpretations affect the resultant measure
- ISO standard takes a one size fits all approach

  One procedure for all users and applications, pulse lengths, wavelengths, damage morphology

- This talk introduces the thoughts behind a US National (OEOSC TF7) proposal for revision

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Overview Of Laser Induced Damage

- Analysis germane to thin film coatings on optical substrates.
- Laser damage can occur through either intrinsic or defect driven mechanisms.
- Intrinsic damage can Include absorbative processes or multiphoton ionization.
- In most dielectrics however the onset of damage is well below the intrinsic threshold and driven by defects in the film.
- This talk Introduces the thoughts behind a US national (OEOSC TF7) proposal for revision based on a test designed to interrogate a defined area and find these defects

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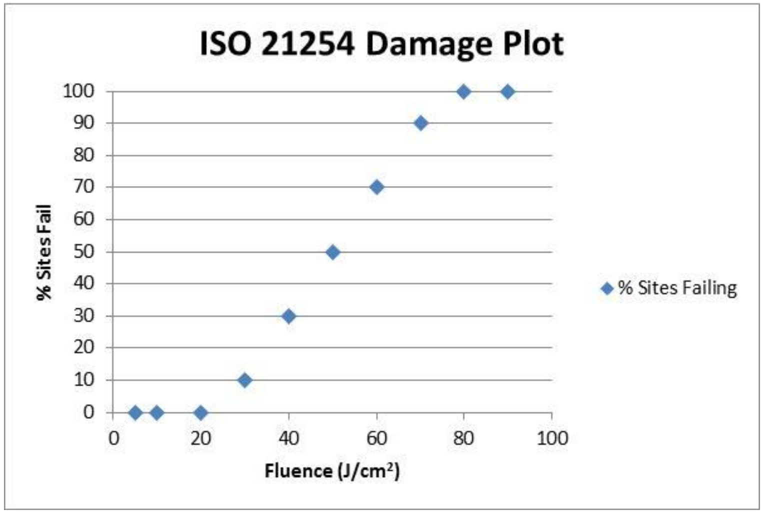
Defect Driven Density Model

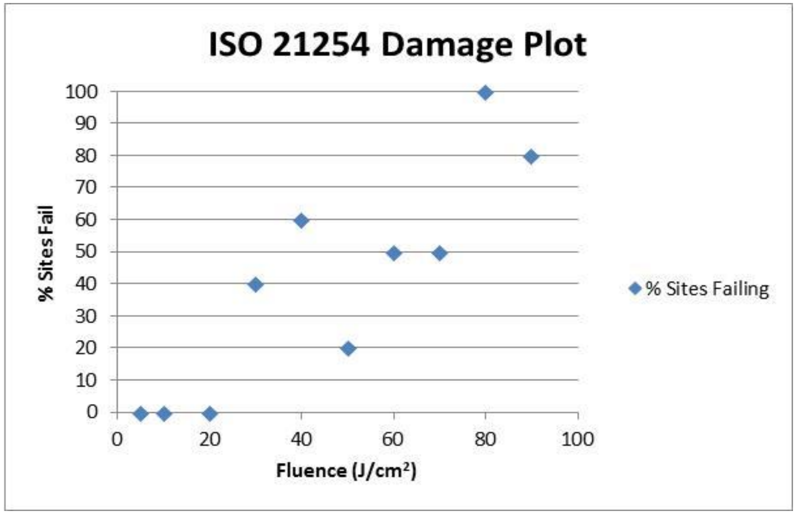
- Laser damage level Is driven by defects in the optical surface
- When performing a test the probability of finding a failing site is a function of the area interrogated, the defect density of the sample and the test fluence.
- Data generated is highly dependent on laser spot size and the area interrogated when the test is performed.
- Variance In area between tests and choice of test locations can lead to variance the measured damage threshold.

Current ISO Approach

- Test is performed under current standard by choosing laser spot size, and testing multiple locations with increasing laser fluence levels In a fixed number of sites.
- Percentage of sites which fail at a given laser fluence determined. Plot of % sites which fail as a function of fluence generated
- Linear regression performed on data
- The abscissa of the linear regression fit defines damage threshold

Current ISO Approach





Ideal Case

Typical Case

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Inconsistencies In ISO 21254

- Regression fit correlation often poor for defect driven optical components
- Fit is highly dependent on correlation between defect distribution and beam spot size.
- A 1 mm ($1/e^2$) diameter beam is only 180 microns at the 90% point of the beam. (Most “work” done in a small aperture)
- One way to counteract is to measure many sites near the damage threshold. Increases confidence in the data. *Maximum Likelihood Estimation (MLE)* method developed by Neyer.

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Current TF7 Approach

- Based on A test procedure developed for National Ignition Facility at LLNL.
- Designed to scale small test area to large optical components
- Test defined area at fixed fluence, by raster scanning laser beam
- Increase fluence by fixed amount and rescan same area
- Observe the number of damage occurrences at each fluence level

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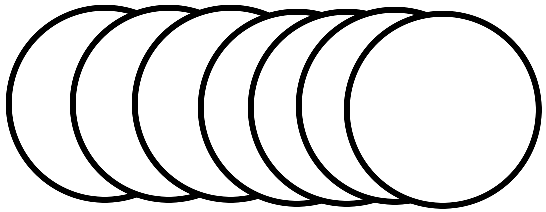
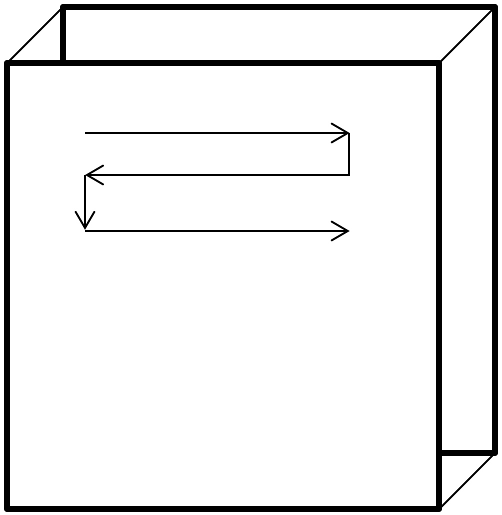
Current Scanning TF7 Approach



Beams Overlap at 90% of
Gaussian Beam Diameter



Sample Scanned In
Serpentine Raster

Now That We Have A Test Procedure

- Scanning allows significant area to be interrogated
- Number of damage sites as *f* (Fluence) can be used to infer defect density and distribution in film
- Damage characteristics and subsequent inspection can differentiate between defect driven and intrinsic damage

TF7 Identifies Two Kinds of Users- Different Needs

- Type 1: Commercial User
  - Can I use this part?
    - Make clear useable aperture
  - How certain is my knowledge in “safe use”
  - Do “good” parts survive?
  - Are the results repeatable (inter-lab comparison)
    - Not dependent on procedure, laser spot, etc
  - How much damage can be tolerated before laser or optic fails.
  - Is my answer dependent on the “model” used?
    - Can I avoid models altogether?
- Type 2: Research User
  - Have the damage characteristics changed?
    - How have they changed?
  - How subtle a change can be detected

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TF 7 Is addressing the Type 1 user first.

Addressing the Type 1 User

- General, easy to implement test process that applies over many use cases
  - Provides inexpensive quick measurements as well as high confidence more expensive tests
  - Allows end use to define confidence level and tailor that level to the required application
  - Provides functional damage test that can be understood by most users.

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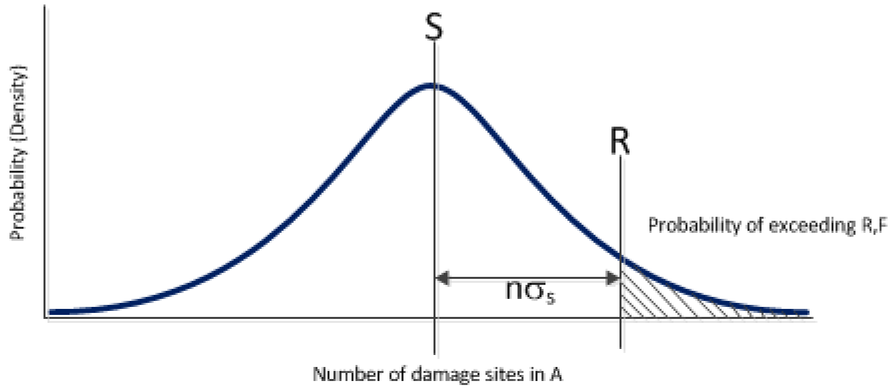
Test Procedure Background and Overview

- Most Type 1 users want to know if a given part will survive in a system
  - Can be thought of as allowing
    - A number of sites damaged
    - A total area damaged

- User specifies the maximum number of allowable damages. S, on the optic of area A and the probability (tolerable risk), R, that the true value is larger than S

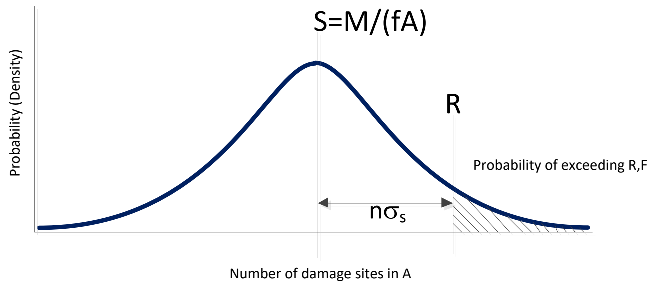


- This test can be specified in terms of either the number of sites that damage or in terms of area lost (sites*area/site)

Laser Damage Procedure

- Step 1 – Calculate the probability of not exceeding R damages in A, P
  - $P = 1 - F$ (1)

- Step 2 – Using Figure 1 determine, n the number of standard deviations of offset needed.

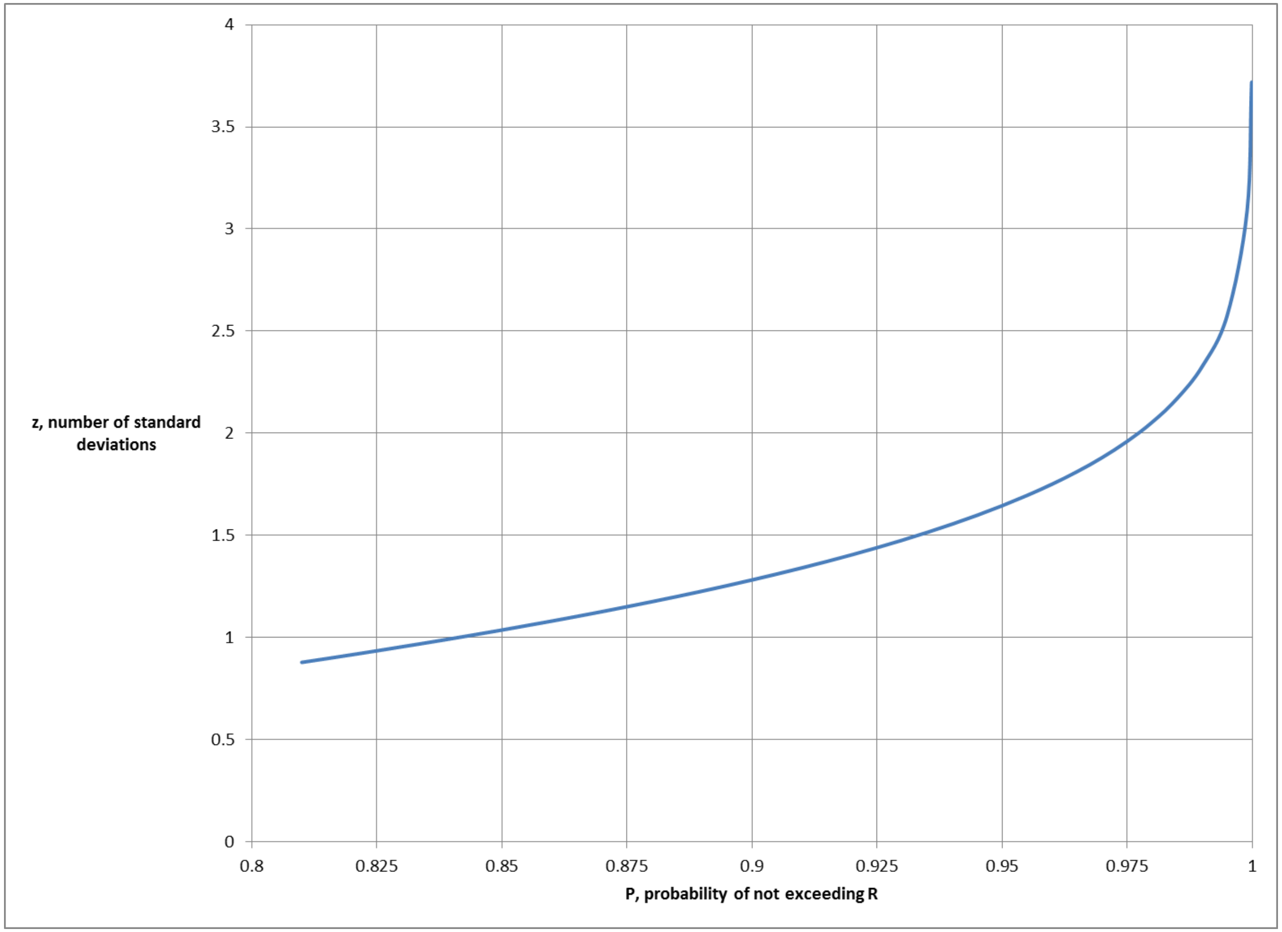


- Step 3 – Determine the upper limit of the number of observed damages, M that can be observed in fA (the area tested, f is the fraction of A exposed), to be at least P likely to have R damages or less in A.
  - $M = fR - \frac{1}{2}n^2 - \frac{1}{2}n\sqrt{(n^2 + 4fR)}$* (2)

Laser Damage Procedure Concept

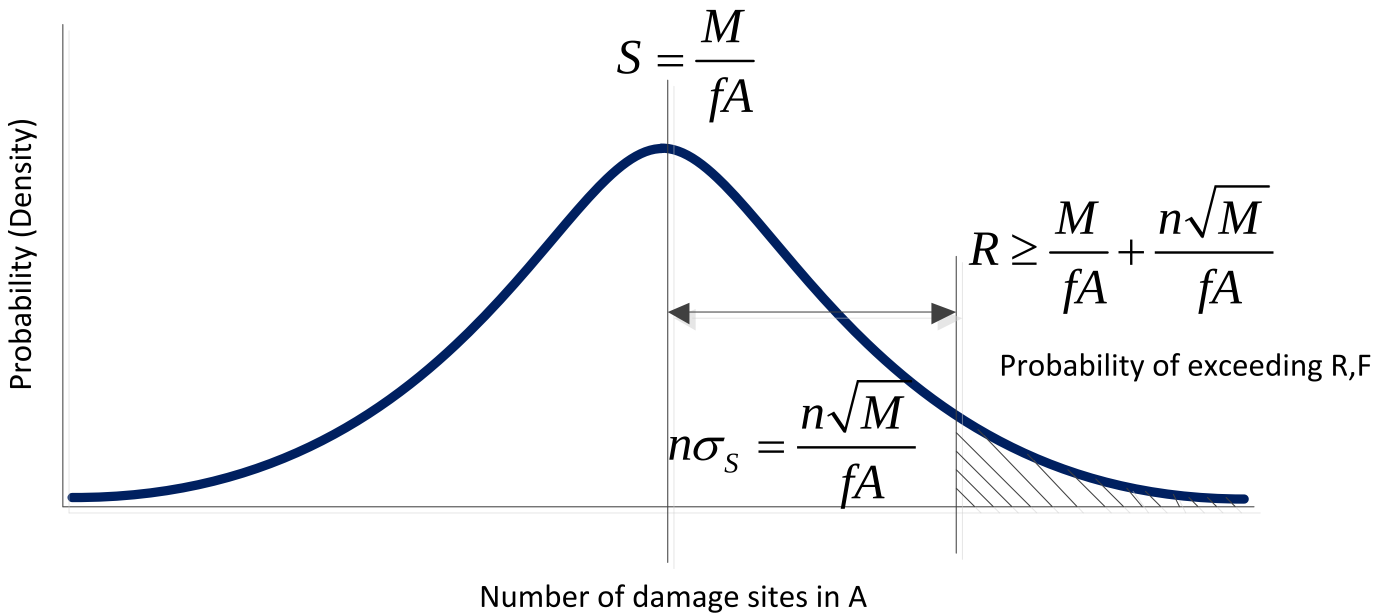
* I (JWA) will happily provide the derivation of this equation. It should go in usage notes or a paper, not in the standard.

Figure 1



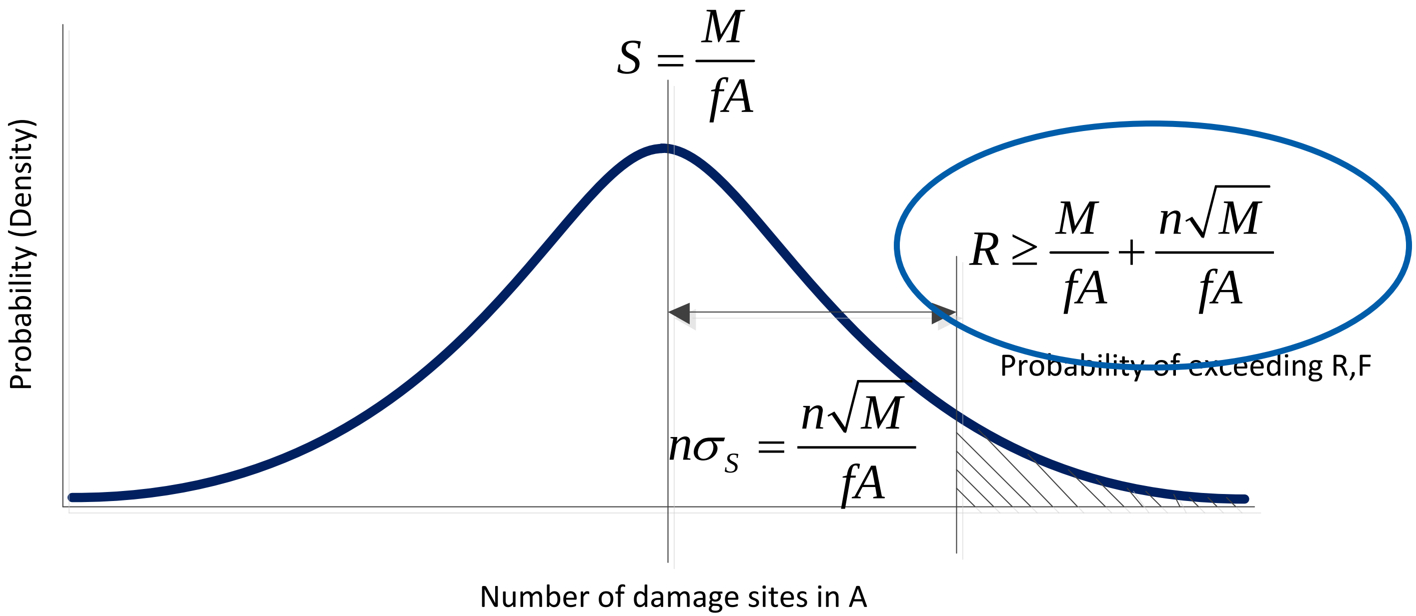
NB: This is possible since the Poisson curve can be well approximated by the Gaussian curve, making this calculation trivial in Excel, Matlab, Mathcad etc.

Explaining (2)



- M and therefore S are described by Poisson statistics

Explaining (2)



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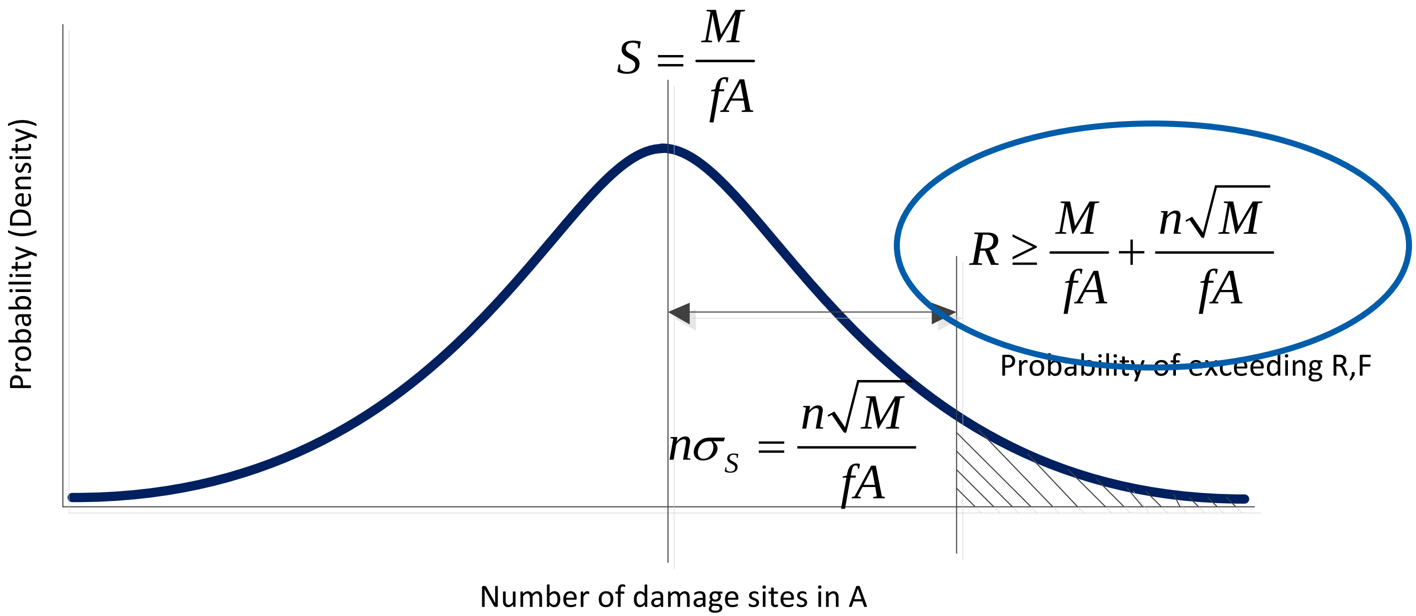
Explaining (2)

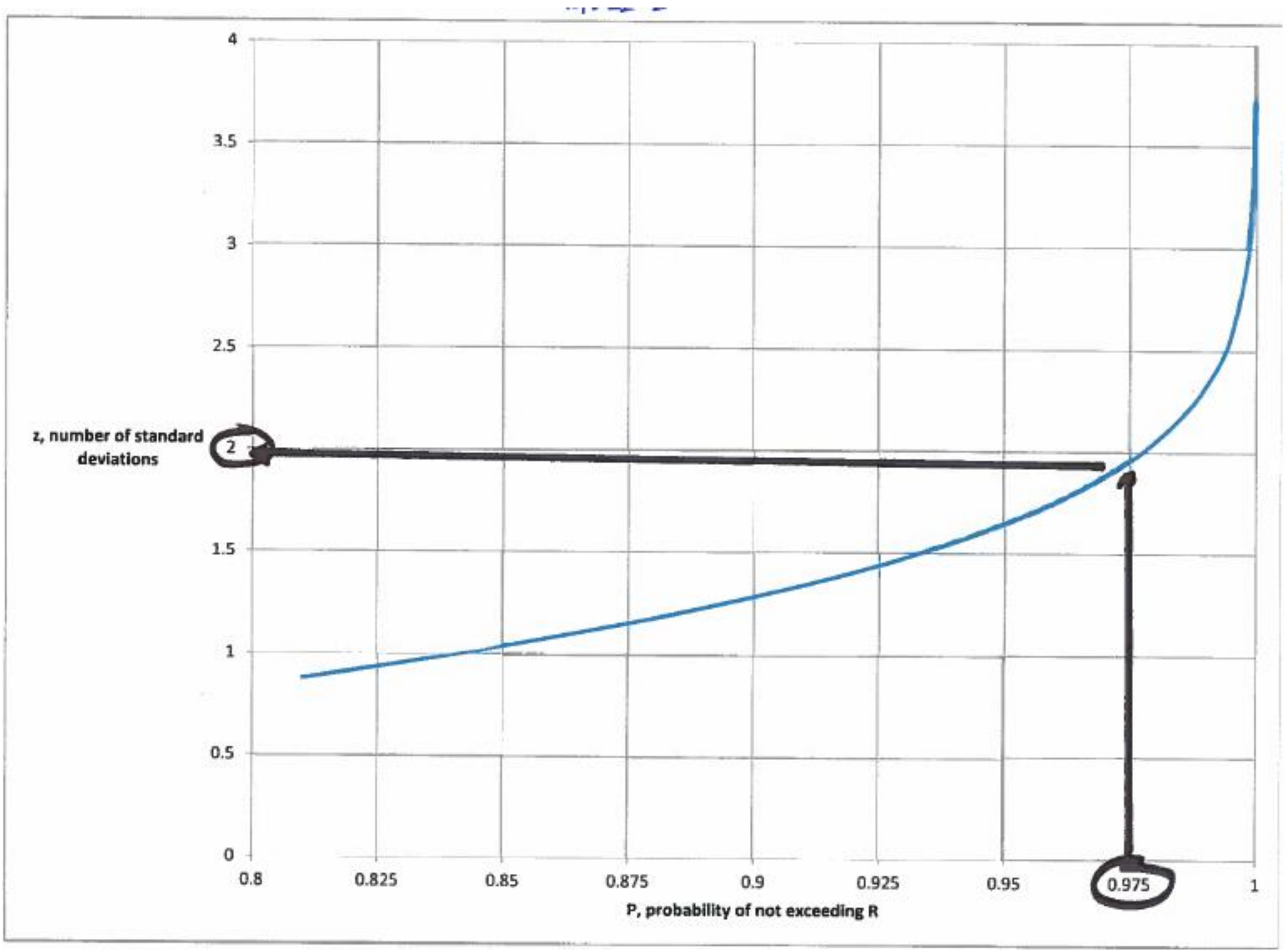


- M and therefore S are described by Poisson statistics
- In Poisson statistics, the mean and variance have the same value
- The solution to n, is found by solving the quadratic in √M which is (2)

Laser Damage Procedure: Example

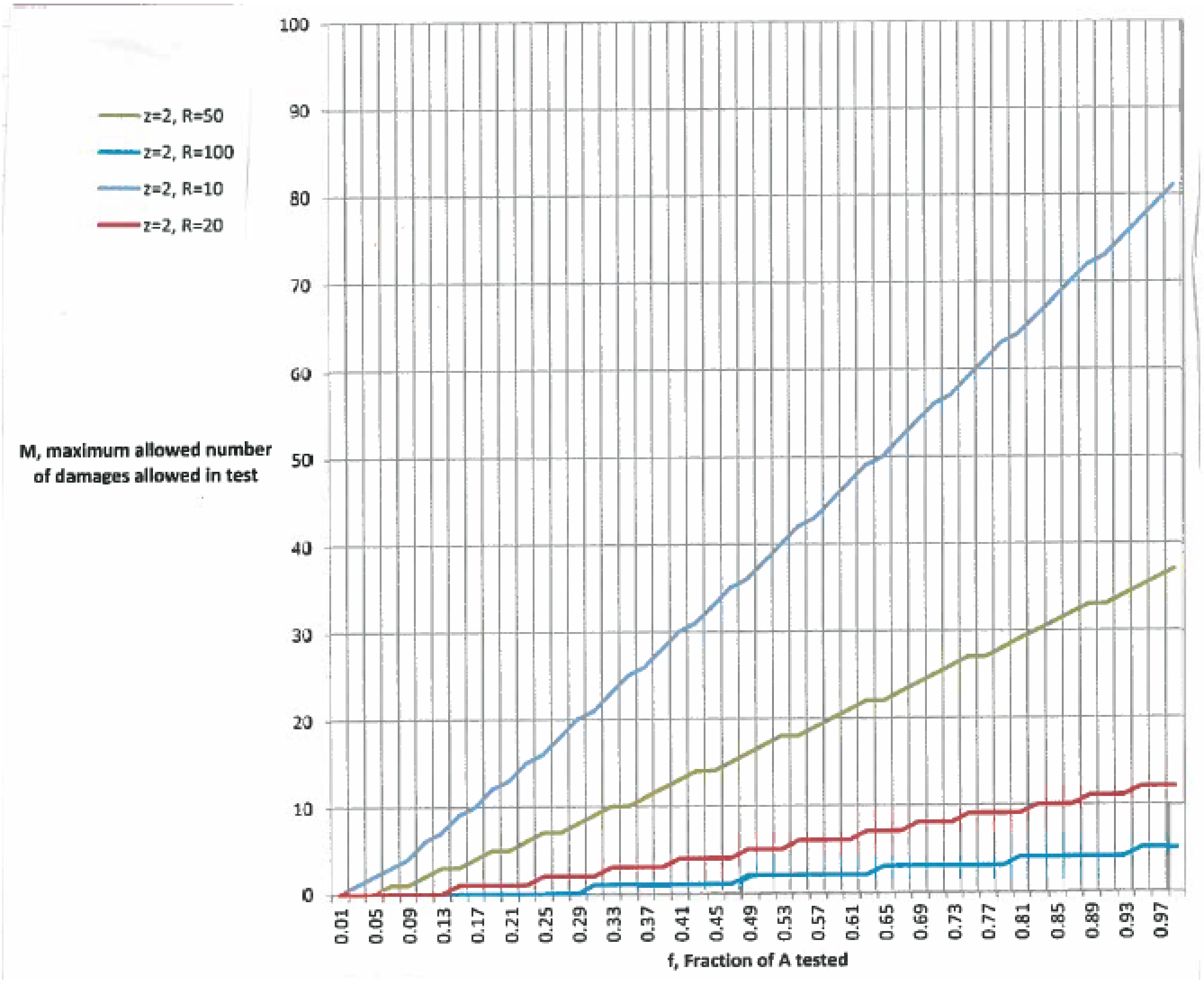
- The user wants to have less than 0.025 chance of having more than R damages on A. So F=0.025
  - P = 1 - 0.025 = 0.975 from (1)
- From Figure 2, we see that n~2. Equation (2) can then be evaluated for various values of R.
- The results are shown in Figure 3 for R = 10, 20, 50 and 100

Figure 2



4
3.5
3
2.5
z, number of standard deviations
2
1.5
1
0.5
0
0.8
0.825
0.85
0.875
0.9
0.925
0.95
0.975
1
P, probability of not exceeding R

Figure 3



z=2, R=50
z=2, R=100
z=2, R=10
z=2, R=20
M, maximum allowed number of damages allowed in test
0
10
20
30
40
50
60
70
80
90
100
0.01
0.05
0.09
0.13
0.17
0.21
0.25
0.29
0.33
0.37
0.41
0.45
0.49
0.53
0.57
0.61
0.65
0.69
0.73
0.77
0.81
0.85
0.89
0.93
0.97
f, Fraction of A tested

Laser Damage Procedure (Cont.)

- Figure 4 shows the hand drown lines of fR for each R with computer plotted values of M. This distance is essentially the "price of confidence"

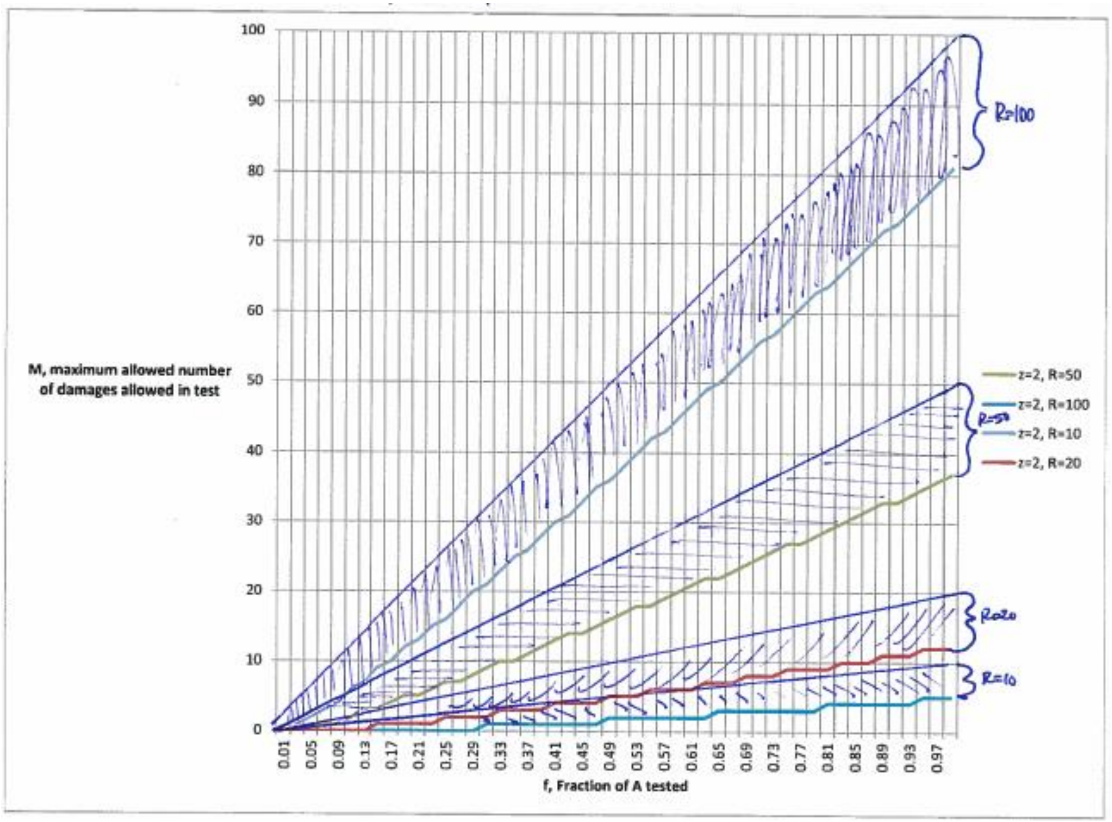
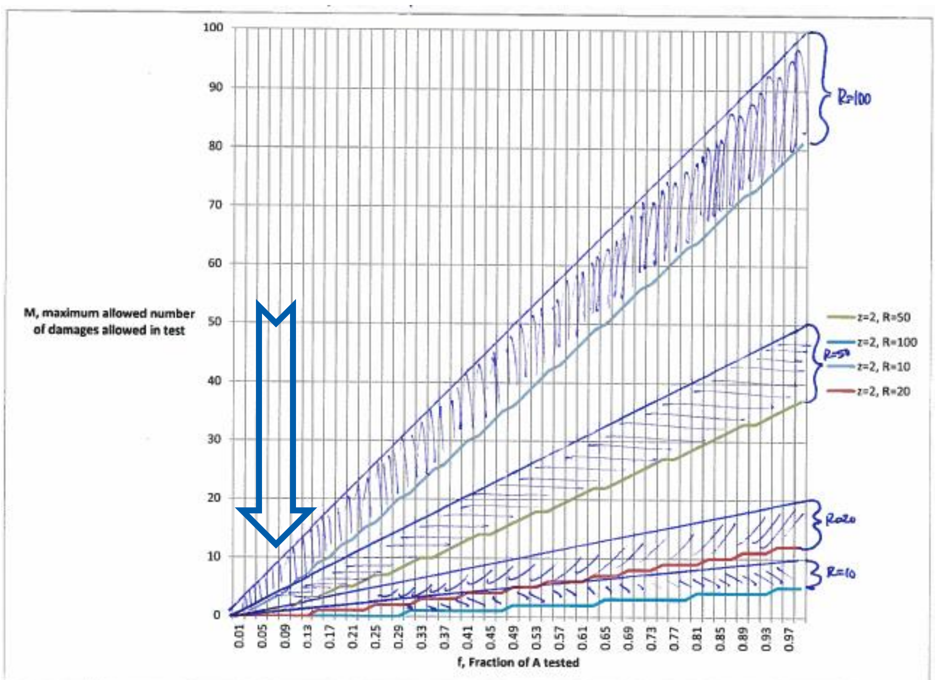


Figure 4

Use Cases

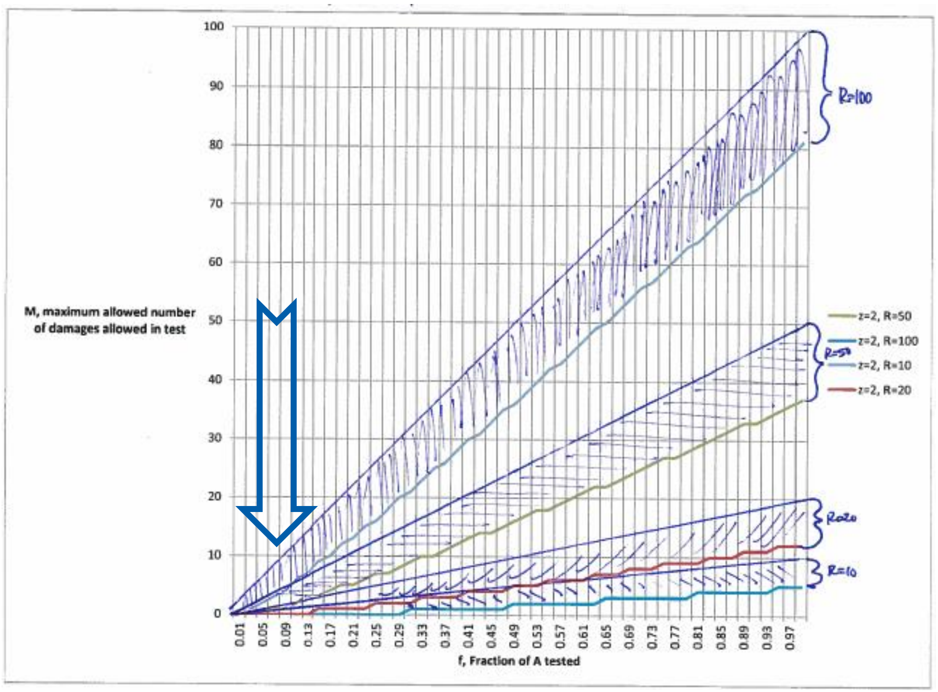
Use Case Analysis: Historical data exists (defect distribution is known)

- In a known and well controlled situation knowledge of f can be used to develop a good small area check
  - Part under test is exposed to higher fluence (and therefore higher cumulative defect density) making



Use Case Analysis: Historical data does not exist

- Testing without any knowledge of f requires large areas to be confident in low defect count
- Low area test cannot differentiate between different values of S
- Only way to be sure is test lots of area (expensive testing)



Summary

- ISO 21254 damage threshold measurement remains satisfactory but can be ambigouos.
- LLNL scanning procedure provides more behaved measurement with results not dependent of test procedure.
- OEOSC has defined a test procedure that is “simple” to use and easy to interpret. Hopefully converging on proper statistical methodology.
- This same procedure can be used to estimate a ***traditional*** on damage threshold (no damage observed) or a ***functiona***l damage threshold (area lost)
- We are seeking input from a wide variety of users, if you have comments or want to submit to the task force, please contact the author.

Acknowledgements

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