Laser Reliability and the 3-D Winds Mission

Michael J. Kavaya
NASA Langley Research Center
michael.j.kavaya@nasa.gov

Working Group on Space-Based Lidar Winds
Wintergreen, VA USA

8 – 11 July 2008

This Talk

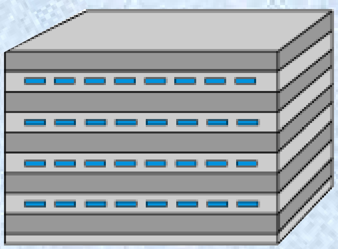
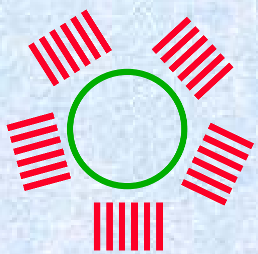
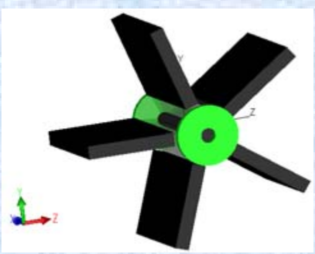
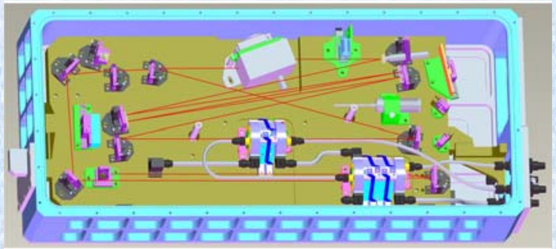
- X Presentation of experimental numbers and the reliability answer
- ☑ Framework for understanding reliability

Reliability of a System

- The reliability of a system comes from the reliability of its parts

For example:

- Many emitters make a laser diode bar
- Many bars make a laser diode array (LDA)
- Many LDAs pump one laser head
- One or more laser heads are in a pulsed laser (oscillator and amplifiers)
- The laser heads, gain crystals, optics, electronics, etc. comprise a pulsed laser
- A pulsed laser plus N spares yields the mission reliability of the pulsed laser


Possible Spares

	Hot Always On	Cold Off Until Needed
Emitters		
Bars	Desired	Not planned
Arrays	Desired	Not planned
Heads	Not Planned	Not Planned
Pulsed Lasers		Yes ✓

Reliability

Reliability = R(t) = Pr { no failure occurs before t }

$\longrightarrow \boxed{A} \rightarrow \boxed{B} \rightarrow \boxed{C} \longrightarrow$

$$R_T(t) = R_A(t) \bullet R_B(t) \bullet R_C(t)$$

$$R(t) = 1 - F(t)$$

Unreliability = F(t) = Pr { failure occurs before t }

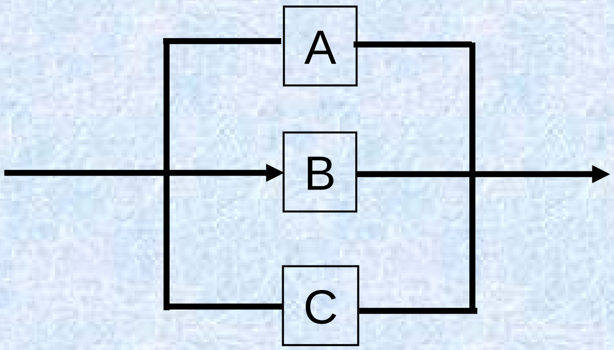
$$F(t) = \int_{-\infty}^{t} f(\tau)\,d\tau$$

f(t) = failure density function

Hot Spares

(all units always on)

Parallel Hot Spares

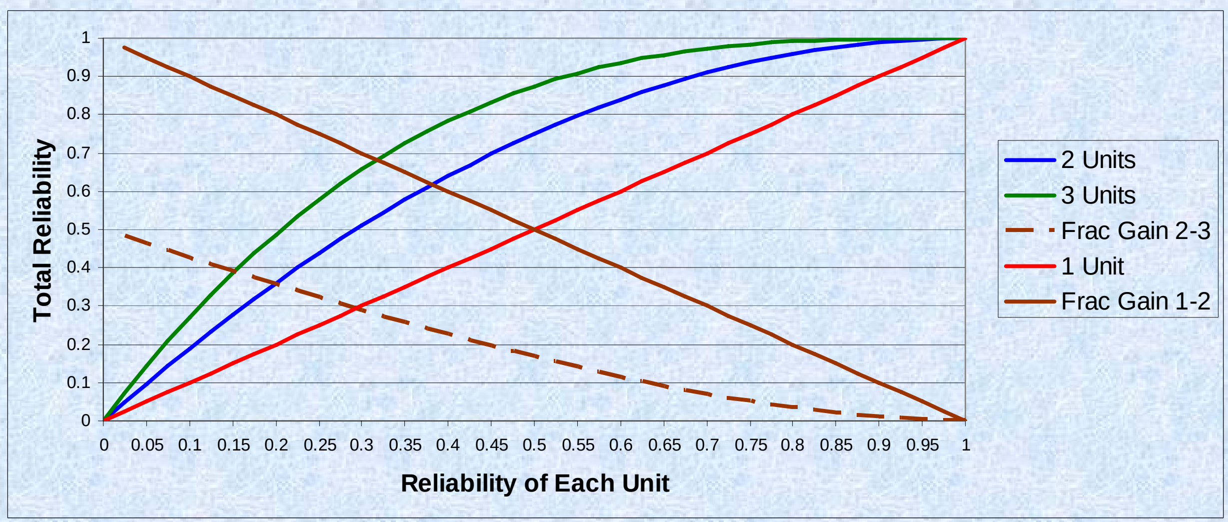


$$T = \mathrm{MAX}(A, B, C, \ldots)$$

$$R_T(t) = 1 - \prod [1 - R_i(t)]$$

2 identical parallel hot spares: $R_T = R\,(2 - R)$

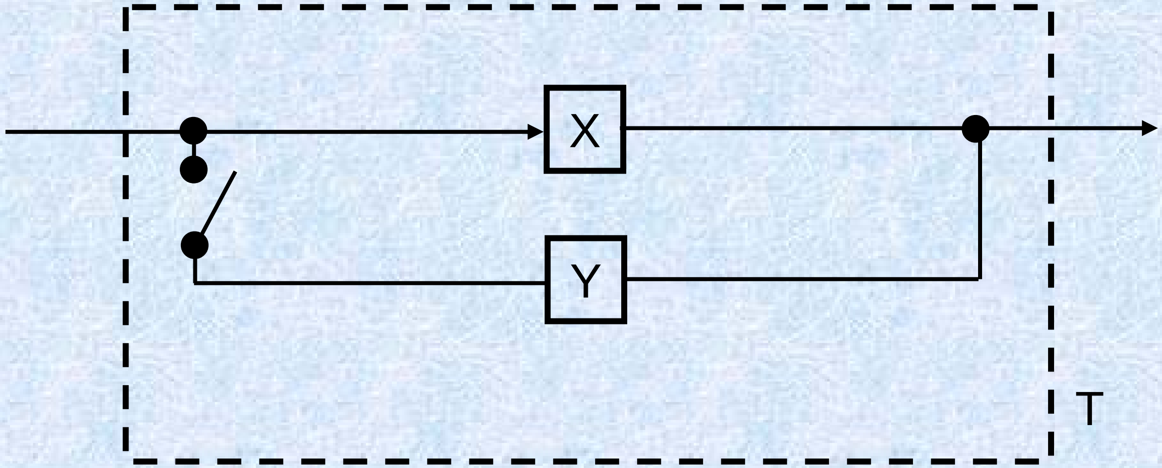
3 identical parallel hot spares: $R_T = R\,(3 - 2R + R^2)$



Cold Spares

(after failure, next unit turned on)

• This is the actual envisioned case for space mission lasers



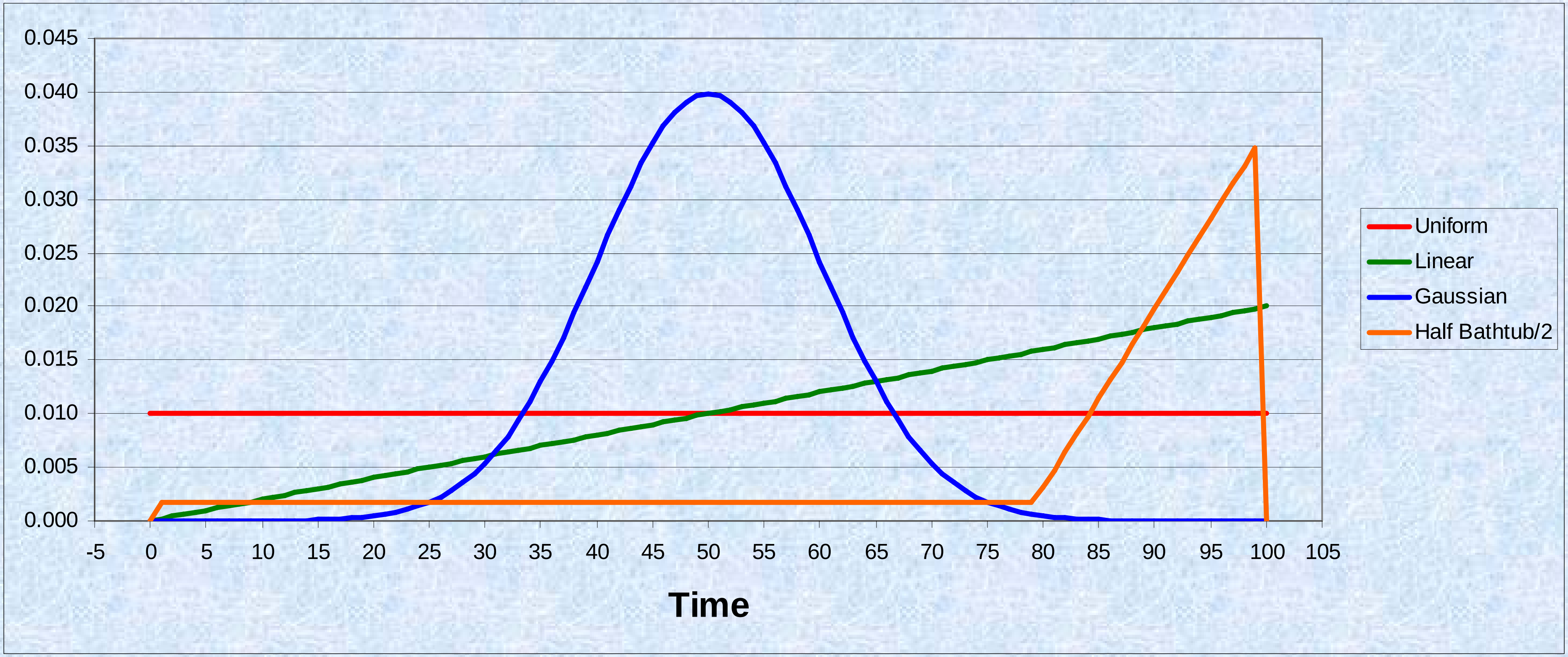
T = X + Y $\Rightarrow$ $$f_T(t) = \int_{-\infty}^{\infty} f_X(t-B)\, f_Y(B)\, dB$$ (convolution)

• There is no single answer. You have to specify the failure density function f of the basic unit.

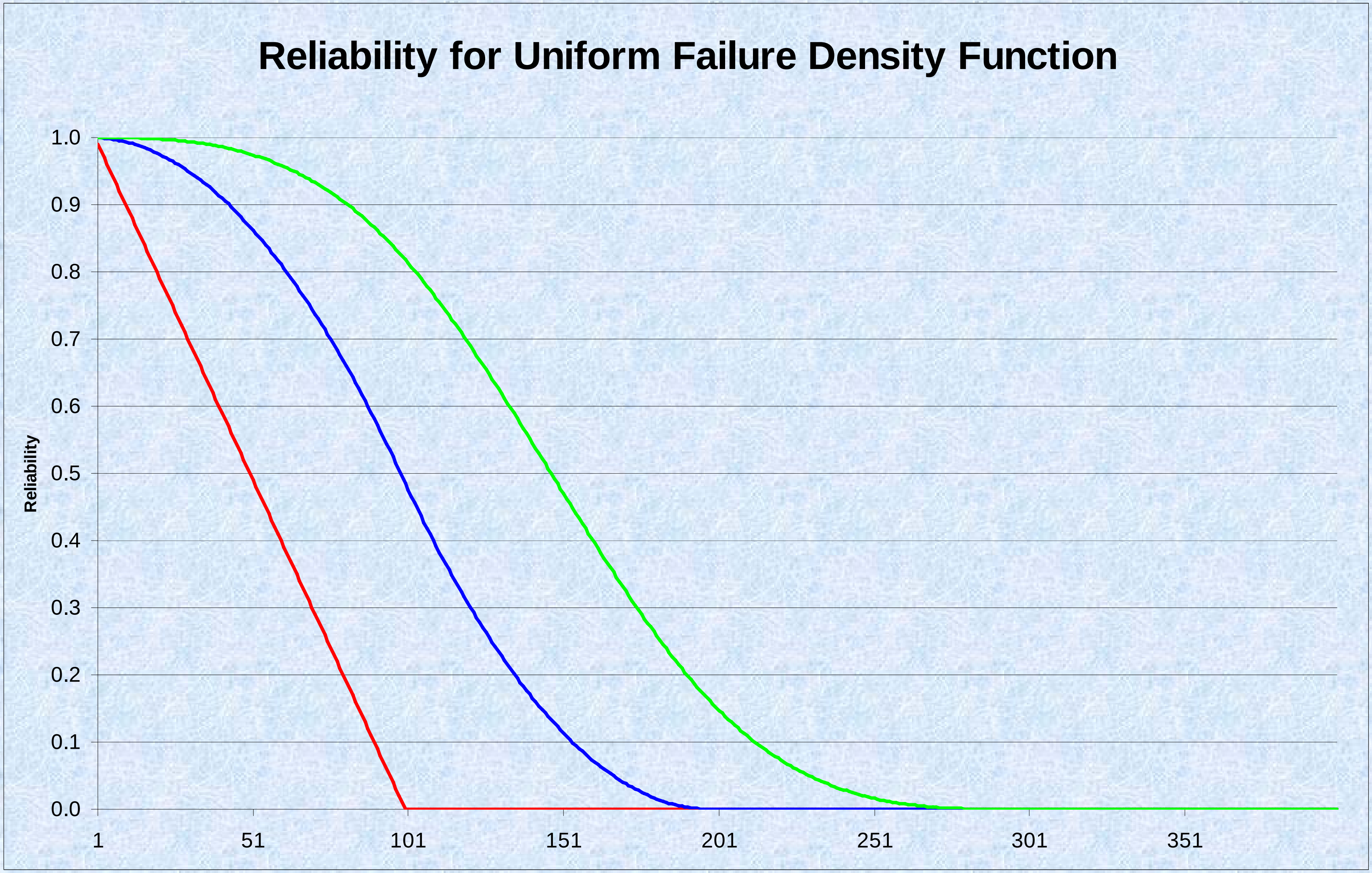
Cold Spares

Example failure density functions

(all time integrals = 1)

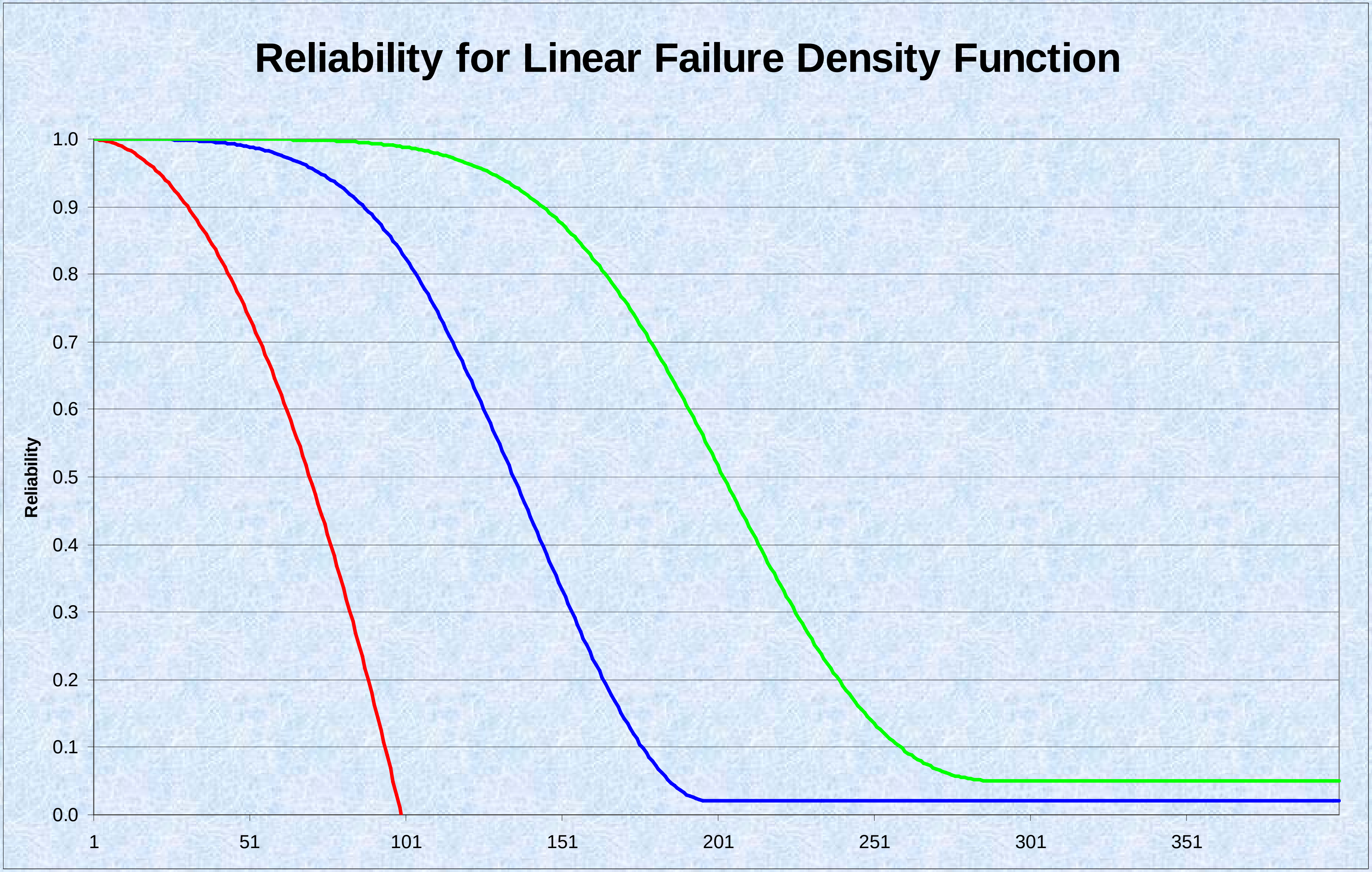


Cold Spares

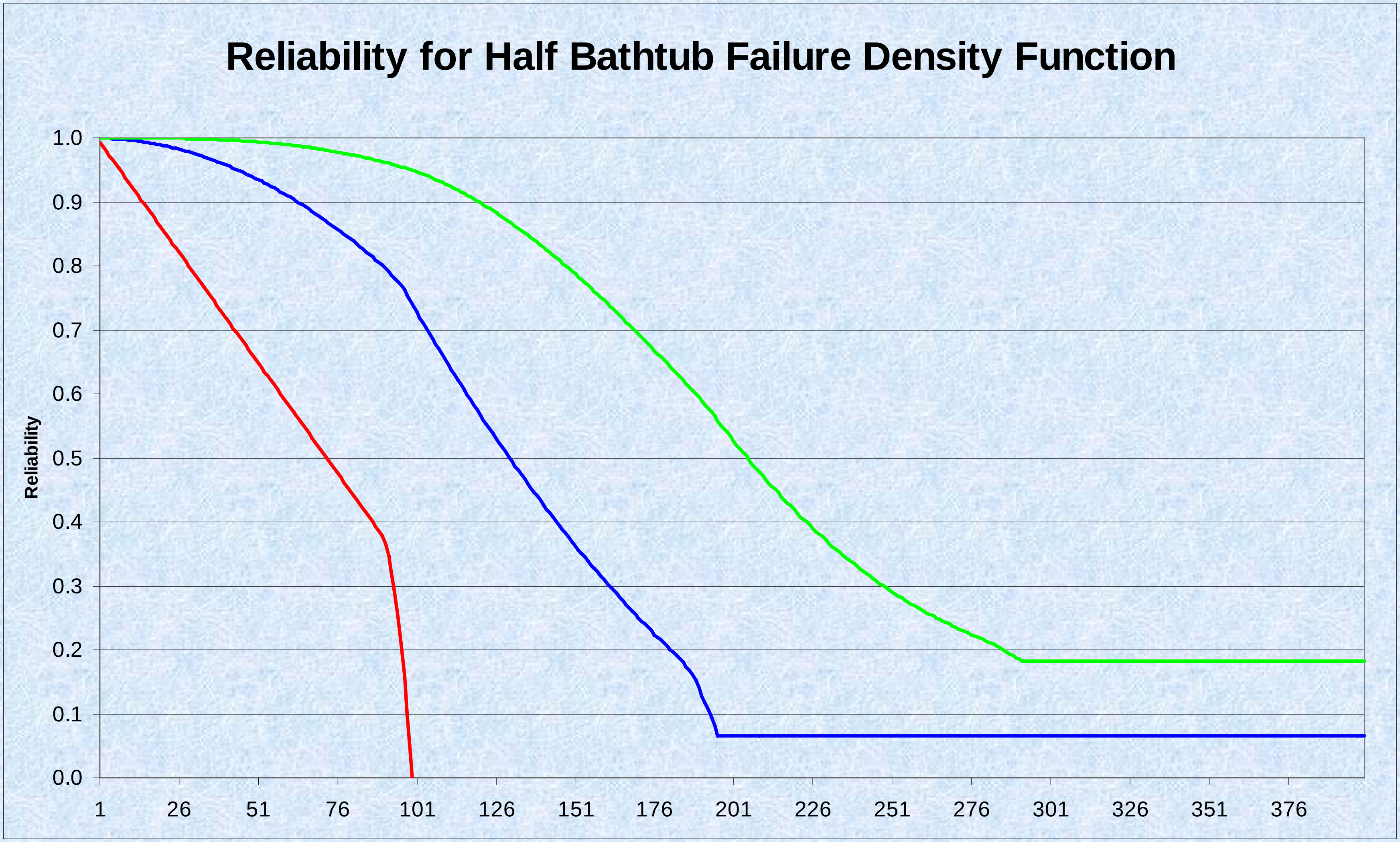


Reliability for Uniform Failure Density Function
Reliability
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
51
101
151
201
251
301
351

Cold Spares

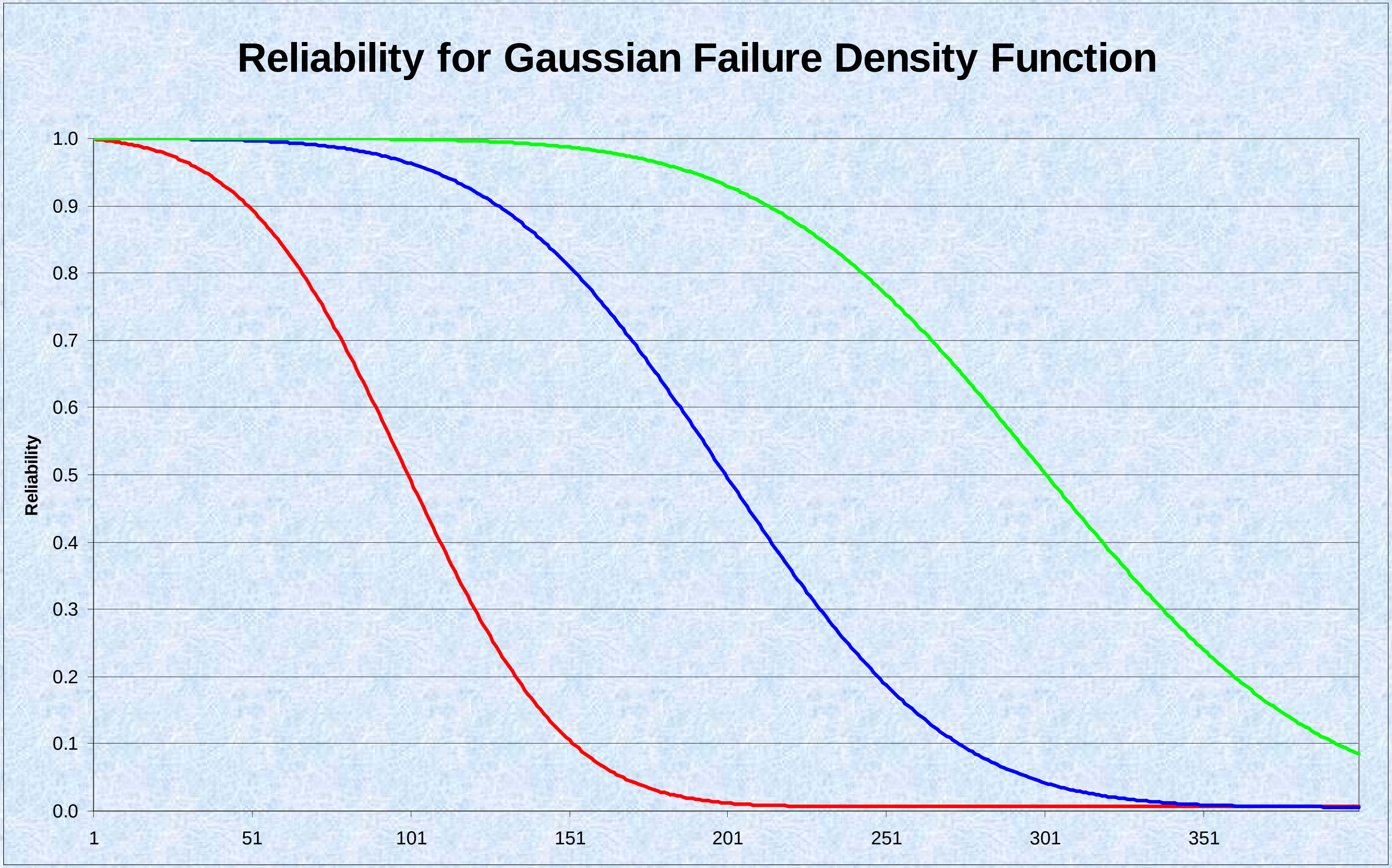

Reliability for Linear Failure Density Function
Reliability
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
51
101
151
201
251
301
351

Cold Spares



Reliability for Half Bathtub Failure Density Function
Reliability
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
26
51
76
101
126
151
176
201
226
251
276
301
326
351
376

Cold Spares



Reliability for Gaussian Failure Density Function
Reliability
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
51
101
151
201
251
301
351

Cold Spares

Gaussian Failure Density Function

• Because a Gaussian convolved with a Gaussian yields a Gaussian with the means and the variances summed, this case has a tabulated function solution for N-1 cold standby spares. Assume all N units are identical with mean M and standard deviation σ:

$$R_T(t) = \frac{1}{2}\left[1 - ERF\left(\frac{t - NM}{\sigma\sqrt{2n}}\right)\right]$$

Cold Spares

Gaussian Failure Density Function

$$R_T(t) = \frac{1}{2}\left[1 - ERF\left(\frac{t - NM}{\sigma\sqrt{2n}}\right)\right]$$

- For high R discussions, ERF will be: -0.99 to -0.80
- ERF argument, ARG, will then be: -1.83 to -0.91 (t < NM)

$$\text{let } \sigma = \frac{M}{C_\sigma} \text{ (C}_\sigma \text{ is ratio of mean to standard deviation, } > 1)$$

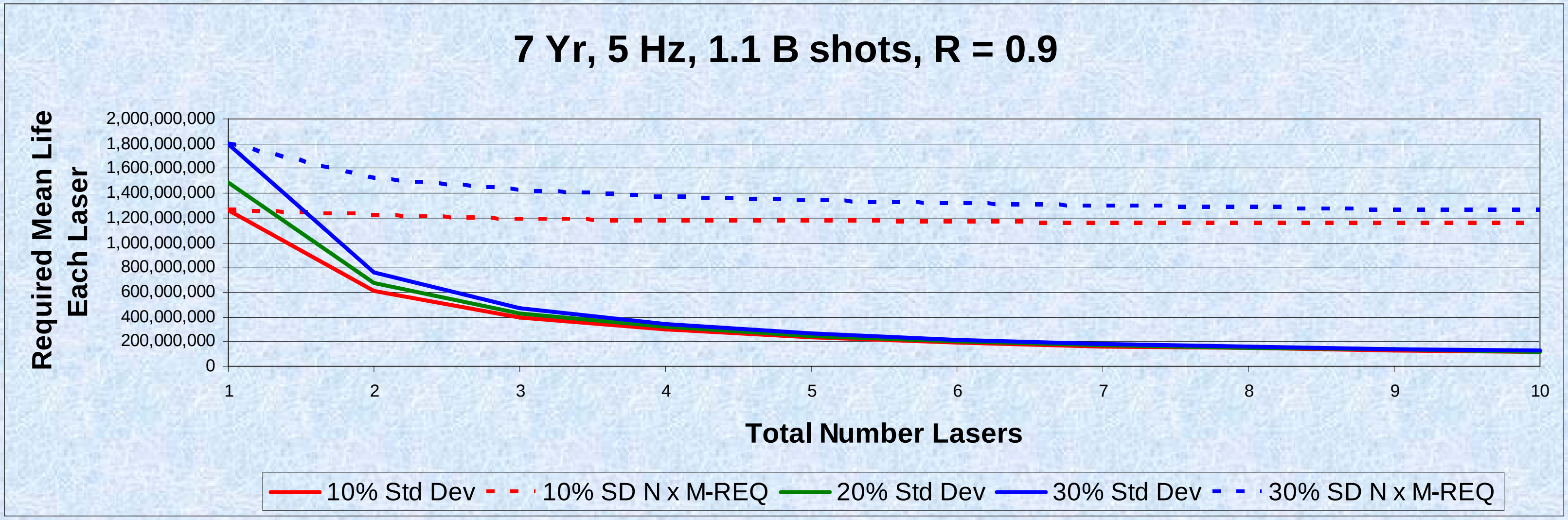
$$\text{and the required overall lifetime} = \text{t}_{\text{REQ}}$$

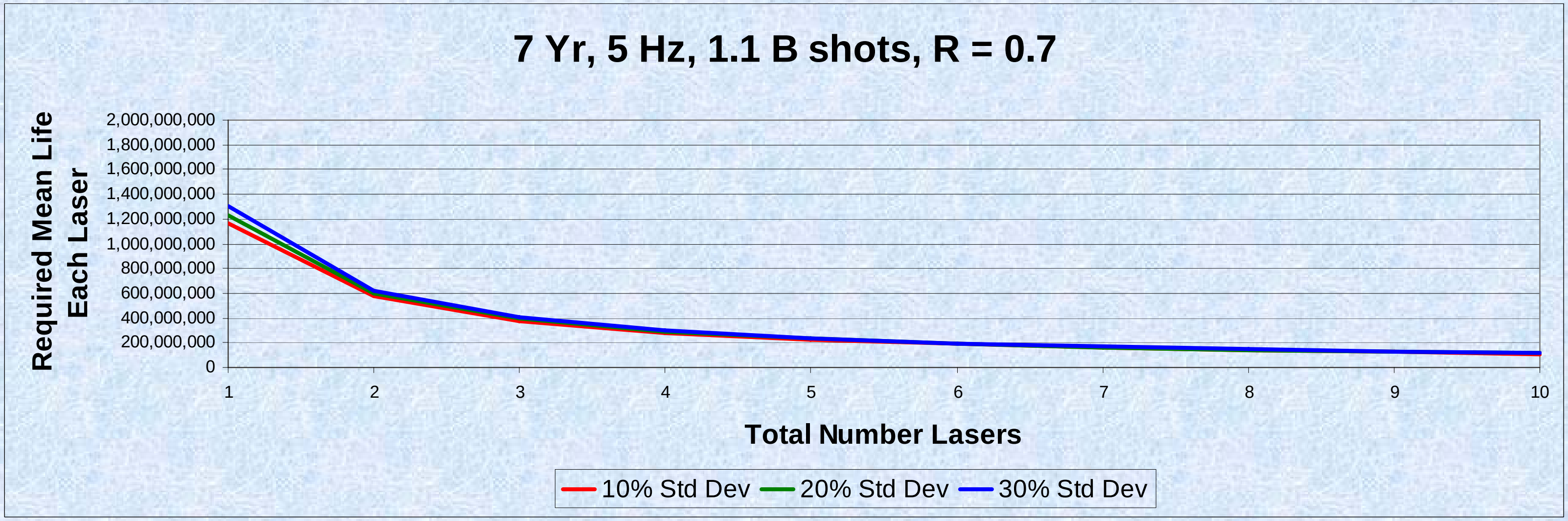
$$\text{then required mean lifetime of each unit M :}$$

$$M_{REQ} = \frac{t_{REQ}}{\sqrt{N}\left[\sqrt{N} - \dfrac{\sqrt{2}ARG_{REQ}}{C_\sigma}\right]}$$

Cold Spares

Gaussian Failure Density Function





NWOS: 1 coherent backup laser

Conclusions

• Lifetime requirement for each laser can be found given overall required lifetime, required reliability, number of cold spares, and failure density function

• Lifetime of individual laser will be achieved with overdesign of laser diode arrays/bars/emitters leading to derating of laser diode array operational current and pulse duration

Back Up

Politicians Software People Cars Computers Electronics God

\- Log Reliability +