



# 850nm VCSELs Reliability analysis

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# Reliability model

# Wear-out reliability model — unreliability function



$$TTF_{x\%} = C \cdot J^{-n} \cdot \exp\left(\frac{E_a \cdot e}{k_B \cdot T_J}\right) = F^{-1}\left(\frac{x}{100}\right); \quad F(t) = \Phi\left(\frac{\ln(t) - \mu'}{\sigma'}\right)$$

$$F(t) = \int_0^t f(\tau) d\tau$$

$$f(t) = \frac{dF}{dt}(t), \quad f(t) \geq 0 \text{ for } \forall t \geq 0, \quad \int_0^\infty f(\tau) d\tau = 1$$

$$f(t') = \frac{1}{\sigma' \sqrt{2\pi}} \exp\left(-\frac{1}{2} \left(\frac{t' - \mu'}{\sigma'}\right)^2\right)$$

$$MTTF = \int_0^\infty \tau f(\tau) d\tau$$

$$TTF_{1\%} = F^{-1}(0.01)$$

$$TTF_{50\%} = F^{-1}(0.5) = \exp(\mu')$$

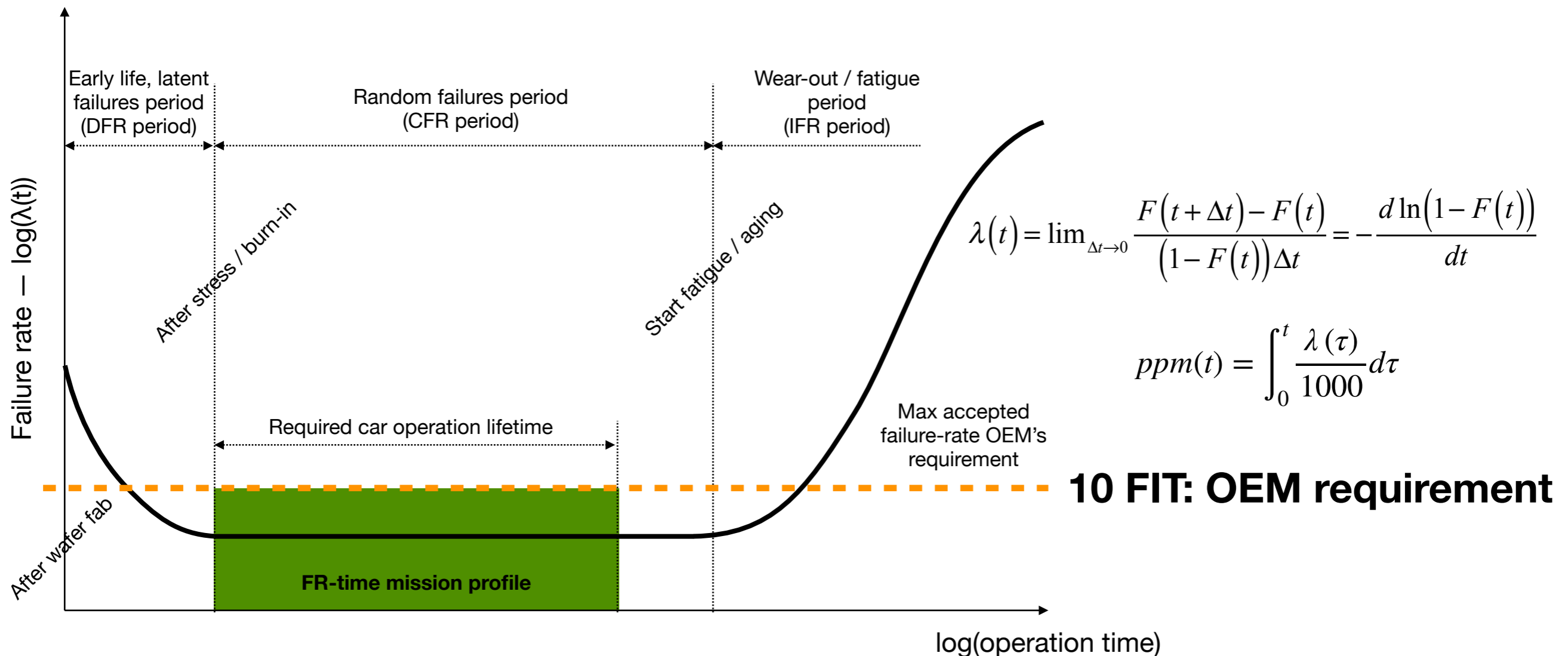
$$TTF_{x\%} = \exp\left(\mu' + \sigma' \cdot \Phi^{-1}\left(\frac{x}{100}\right)\right)$$

- For a given  $t$ ,  $F(t)$  is the probability that failure occurs before  $t$
- $F(t)$  is the cumulative distribution function (CDF) of the failure probability
  - $\Phi$  is the standard normal distribution (i.e.  $N(0,1)$ )
  - $t$  is the time to failure
  - $t'$  is the natural logarithm of the time to failure
  - $\mu'$  mean of the natural logarithms of the time to failure
  - $\sigma'$  standard deviation of the natural logarithms of the time to failure
- Arrhenius's equation
  - $E_a$  is the activation energy of failure mechanism (eV)
  - $e$  is the electron charge (SI units)
  - $k_B$  is the Boltzmann's constant (SI units)
  - $T_J$  is absolute temperature (Kelvin)
  - $J$  is the current density (e.g. in kA/cm<sup>2</sup>)
  - $n$  is the current exponent
  - $C$  is a constant
  - $TTF_{x\%}$  is the time to x% failures (e.g. in hours)

# Reliability model — failure rate



- Pay attention that **in general failure-rate  $\lambda(t)$  is not constant** and depends on how much time the component has survived in operation
- Failure-rate is typically measured in Failures In Time (FIT), number of failures per  $10^9$  (billion) **device-hours**
  - 1 FIT = probability of failure is  $10^{-9}$  / 1 hour (operation)
  - 1 FIT = probability of failure is 1 ppm / 1000 hours
  - 1 FIT = 1 failure per 1000 devices operating 1 million hours = 1 failure per 10 million devices operating 100 hours





# Reliability of 850nm VCSEL

Data and model of king\_3cz\_01\_1120 and king\_3cz\_01a\_0521

Similar analysis of perezaranda\_3cz\_01b\_080621\_vcsel\_reliability at 7.5 mA

# Reliability results (model in T<sub>J</sub>)



Reliability parameters

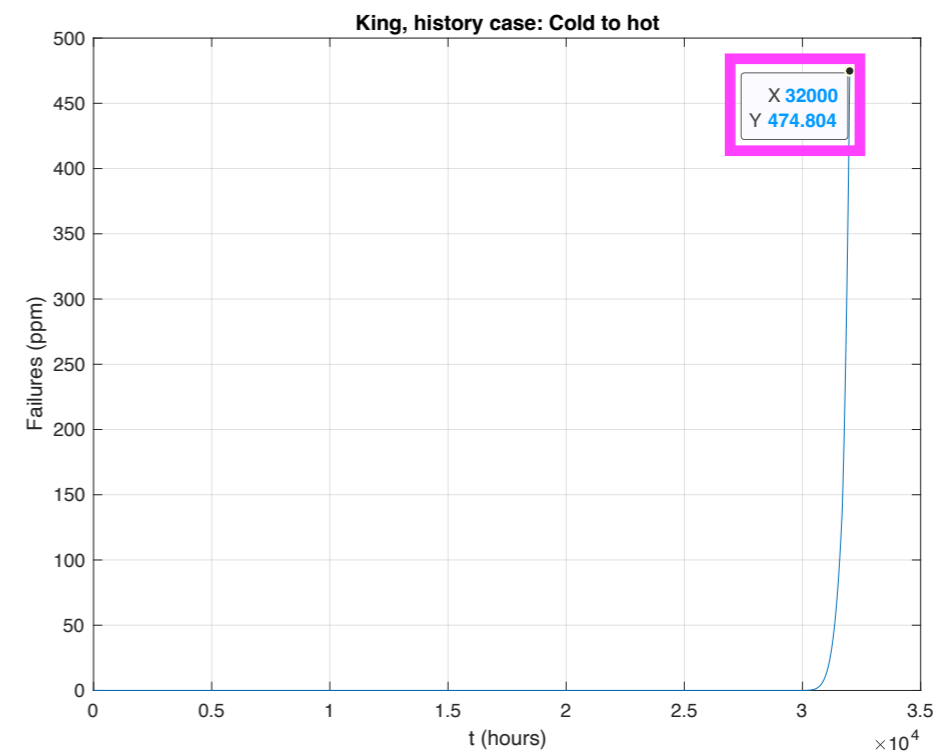
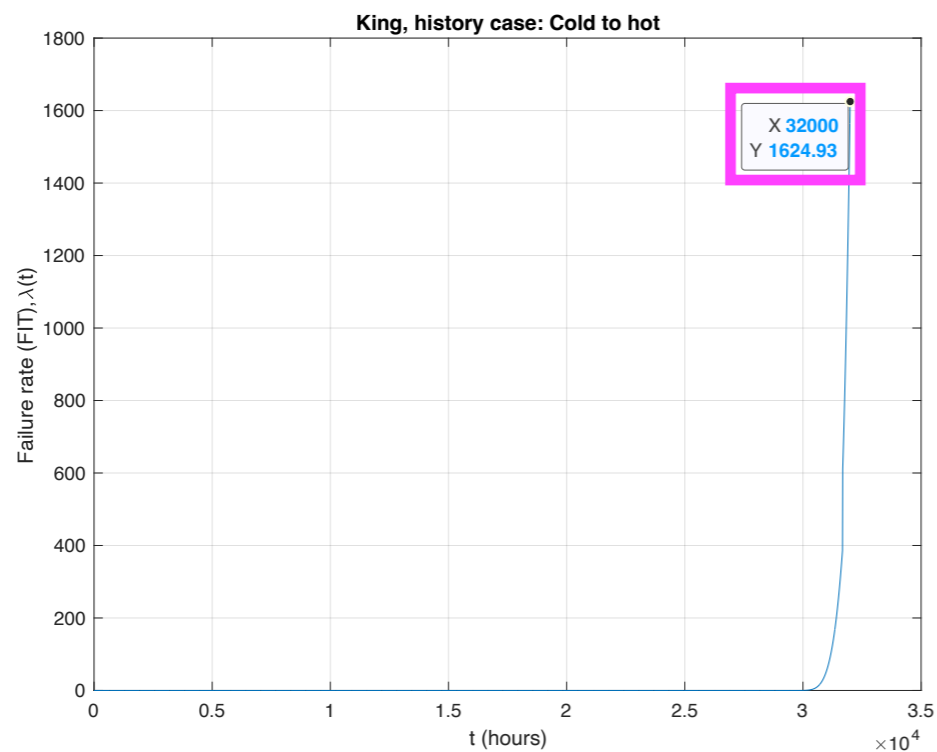
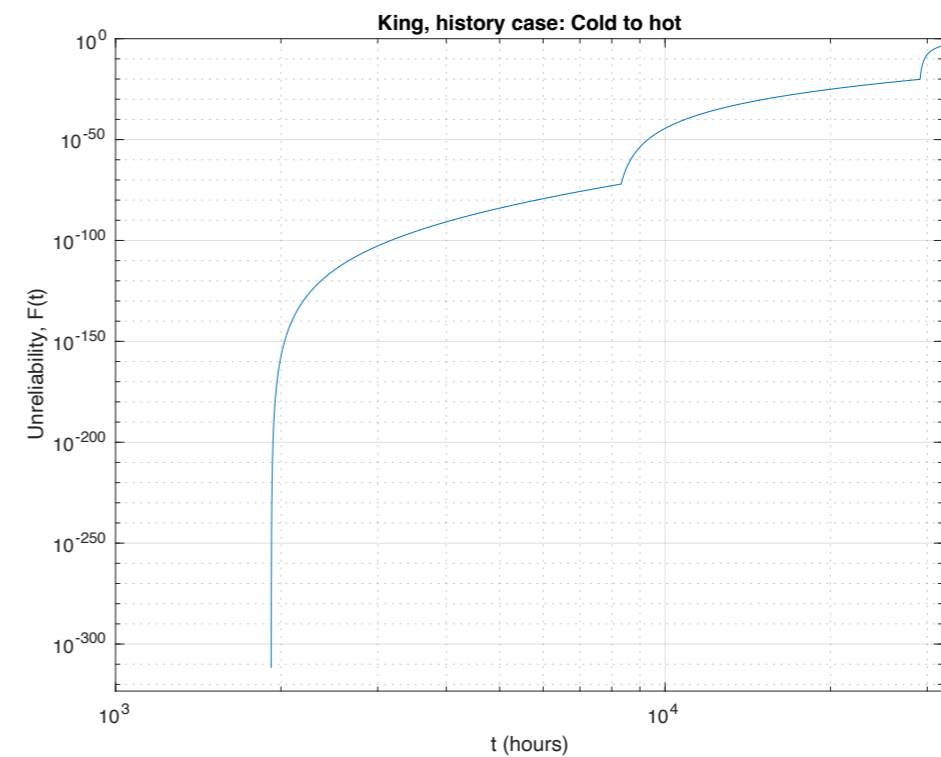
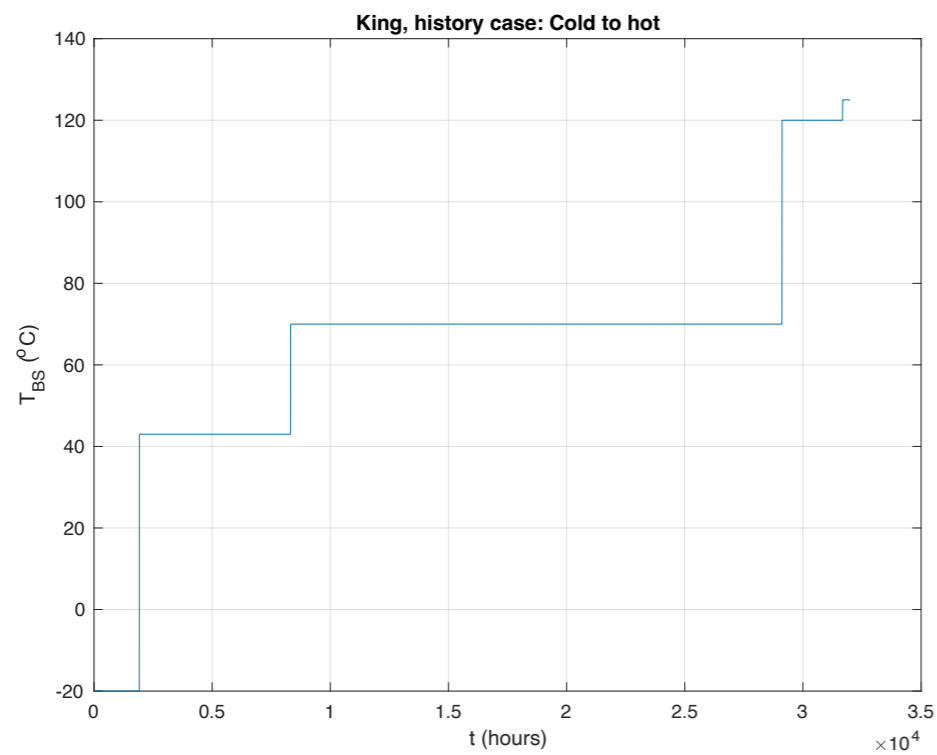
Operation	Operation total time (h)	32000	Reliability model	Wear out Ea (eV) @ T <sub>J</sub>	1.180	
	Service life (years)	15			Wear out n @ T <sub>J</sub>	1.640
	Min oxide aperture diam. (um)	7.0			TTF x%, location	50.0
	I <sub>OP</sub> (mA) max	7.0000			Log-normal σ', ln (hours)	0.5
	J <sub>OP</sub> (kA/cm <sup>2</sup> )	18.20			J <sub>0</sub> (kA/cm <sup>2</sup> )	19.50
	J <sub>OP</sub> (mA/um <sup>2</sup> )	0.18			T <sub>J0</sub> (°C)	193
	ΔT <sub>AS</sub> (°C)	20.0			TTF <sub>0</sub> x% (hours)	965
VCSEL model fitting	R <sub>JS</sub> (K/W) @ room Ts reference	1950	VCSEL model fitting	Arrhenius C factor (hours) @ T <sub>J</sub>	2.200519E-08	
	R <sub>JS</sub> factor	100 %		Q <sub>e</sub>	1.6022E-19	
	R <sub>JS</sub> (K/W) @ room Ts	1950		K <sub>B</sub>	1.3806E-23	
	R <sub>JS</sub> room Ts (°C)	20.0		Q <sub>e</sub> /K <sub>B</sub>	1.1605E+04	
	R <sub>JS</sub> Exponent	1.067		°C to Kelvin	273.15	
	R <sub>JS</sub> Current fitting p0	0.01754		P <sub>DIS</sub> poly-fitting p11	-0.006889	
	R <sub>JS</sub> Current fitting p1	0.9636		P <sub>DIS</sub> poly-fitting p02	-5.203E-05	
	P <sub>DIS</sub> poly-fitting p00	-0.3481		P <sub>DIS</sub> poly-fitting p21	0.0001612	
	P <sub>DIS</sub> poly-fitting p10	1.291		P <sub>DIS</sub> poly-fitting p12	3.641E-05	
	P <sub>DIS</sub> poly-fitting p01	0.01552		P <sub>DIS</sub> poly-fitting p03	1.736E-15	
P <sub>DIS</sub> poly-fitting p20	0.05763					

- Recommended I<sub>bias</sub> = 7 mA for performance

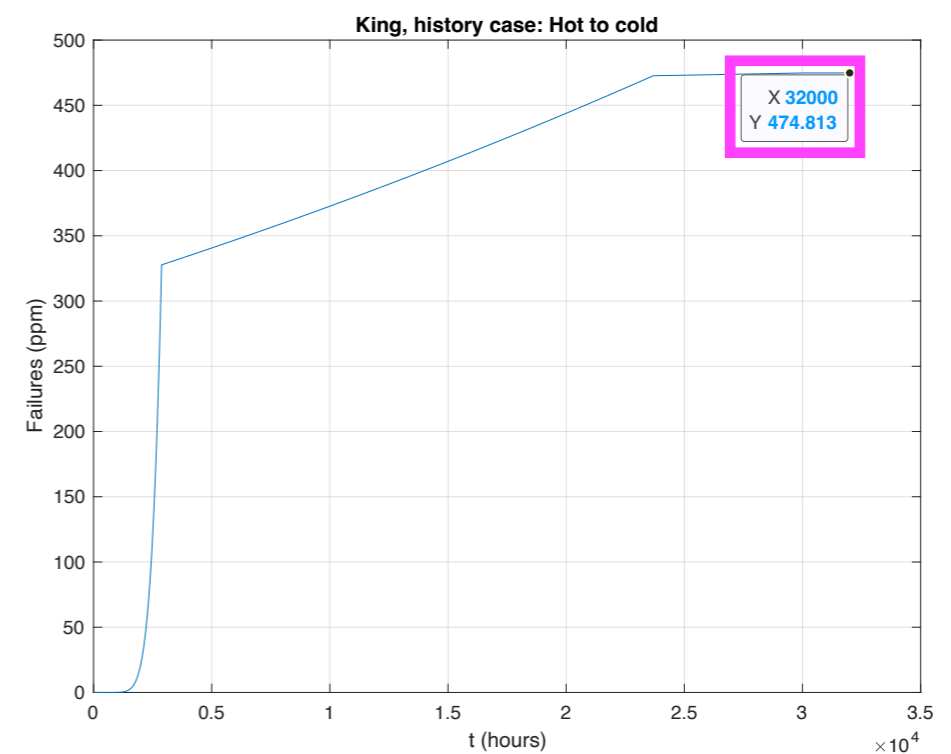
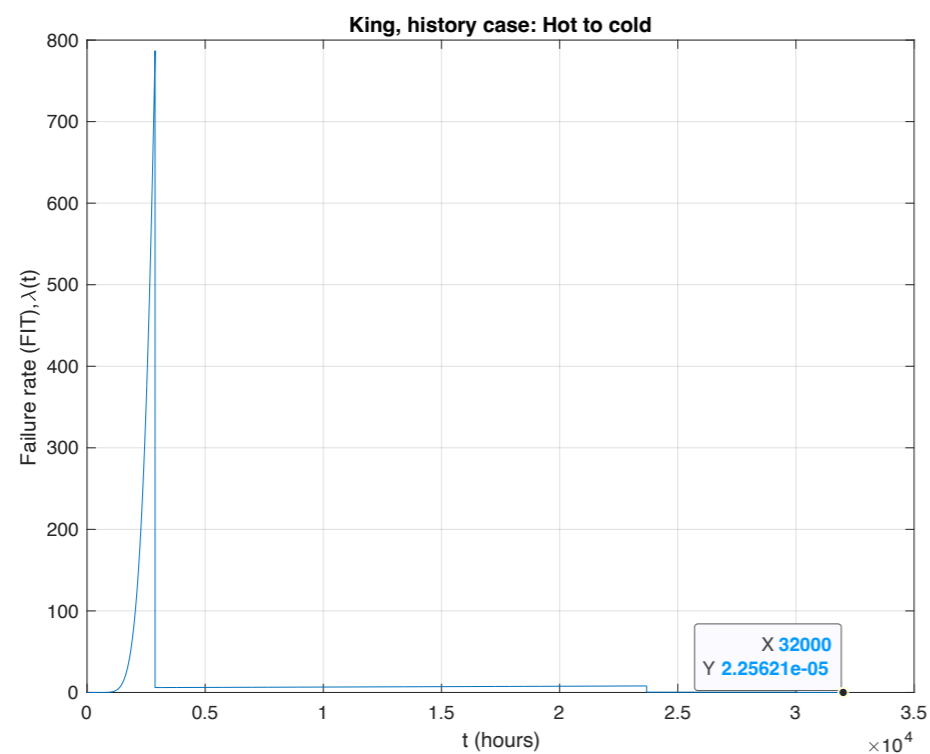
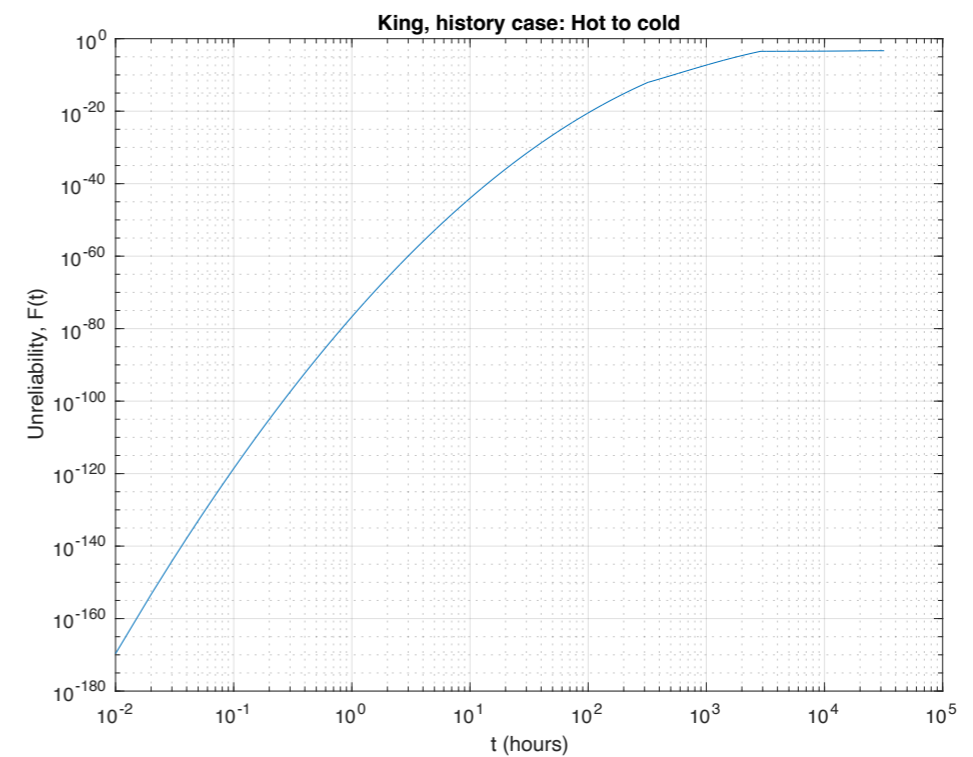
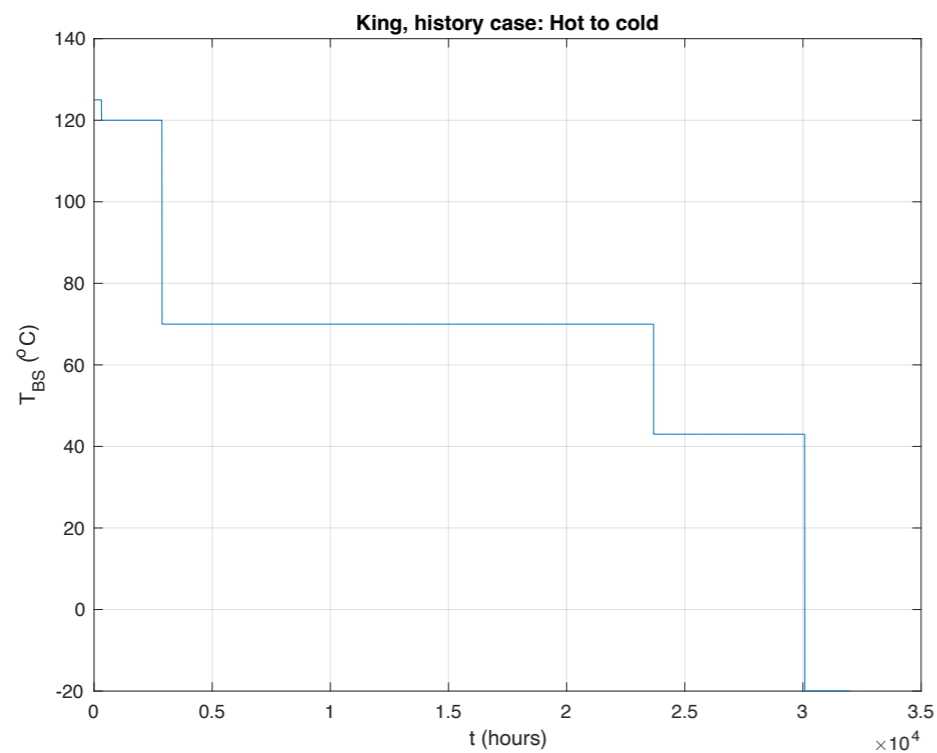
Reliability result

	Temperature profile							Failure rate				
	Percentage	Operation time per Temperature (h)	T <sub>A</sub> (°C)	T <sub>S</sub> (°C)	R <sub>JS</sub> (K/W)	P <sub>DIS</sub> (mW)	T <sub>J</sub> (°C)	TTF x% (hours)	Equivalent time in max T (hours)	Log-normal mu', ln (hours)	Failure-rate wear out (FIT)	
T0	6 %	1920	-40	-20.0	1811.5	12.09	1.9	7.895E+11	0.00	27.3947		
T1	20 %	6400	23	43.0	2296.2	10.82	67.8	5.199E+07	1.34	17.7665		
T2	65 %	20800	50	70.0	2506.1	10.77	97.0	2.202E+06	102.86	14.6048		
T4	8 %	2560	100	120.0	2897.5	11.46	153.2	1.678E+04	1661.56	9.7277		
T5	1 %	320	105	125.0	2936.8	11.58	159.0	1.089E+04	320.00	9.2954		
Cummulative	100 %	32000							2085.76	9.2954	1625.3	

# Failures as function of $T_{BS}(t)$ : cold to hot

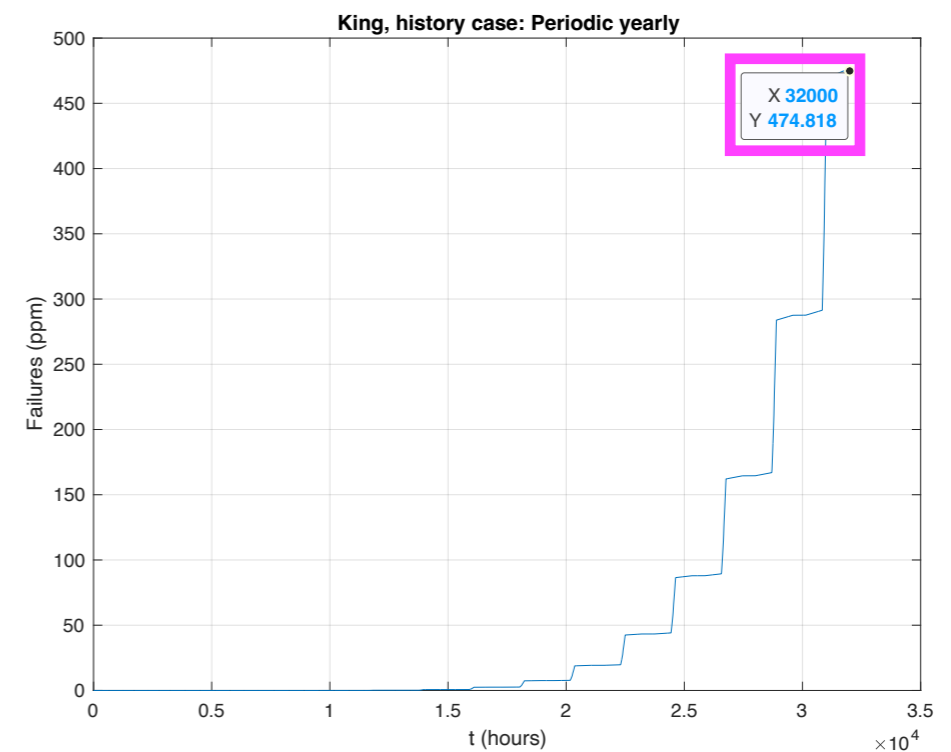
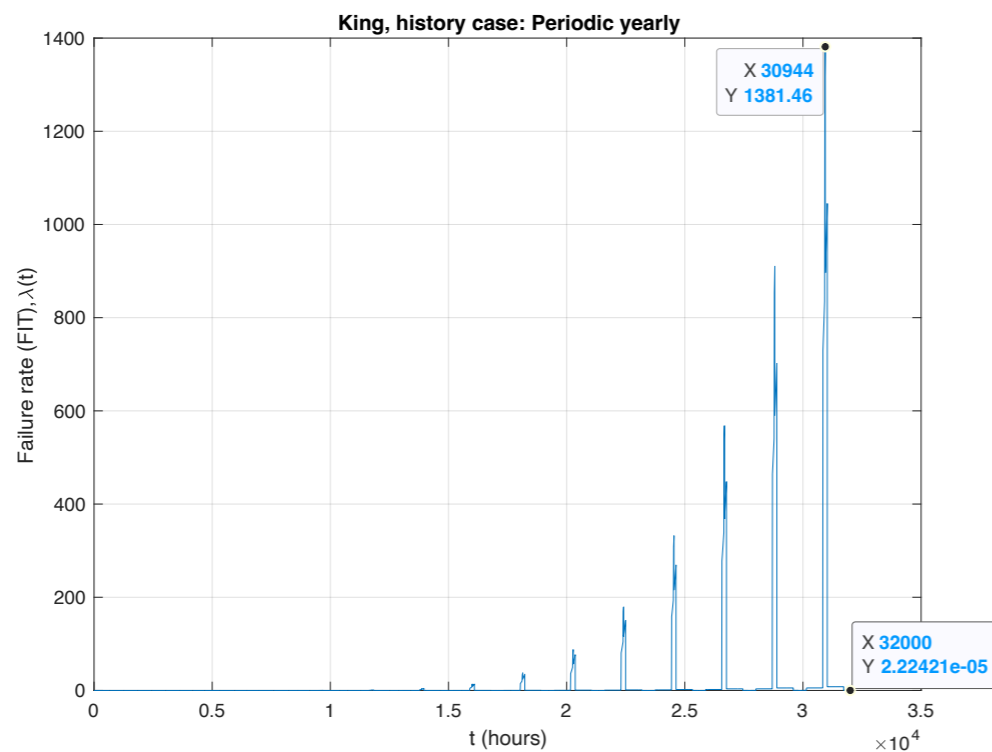
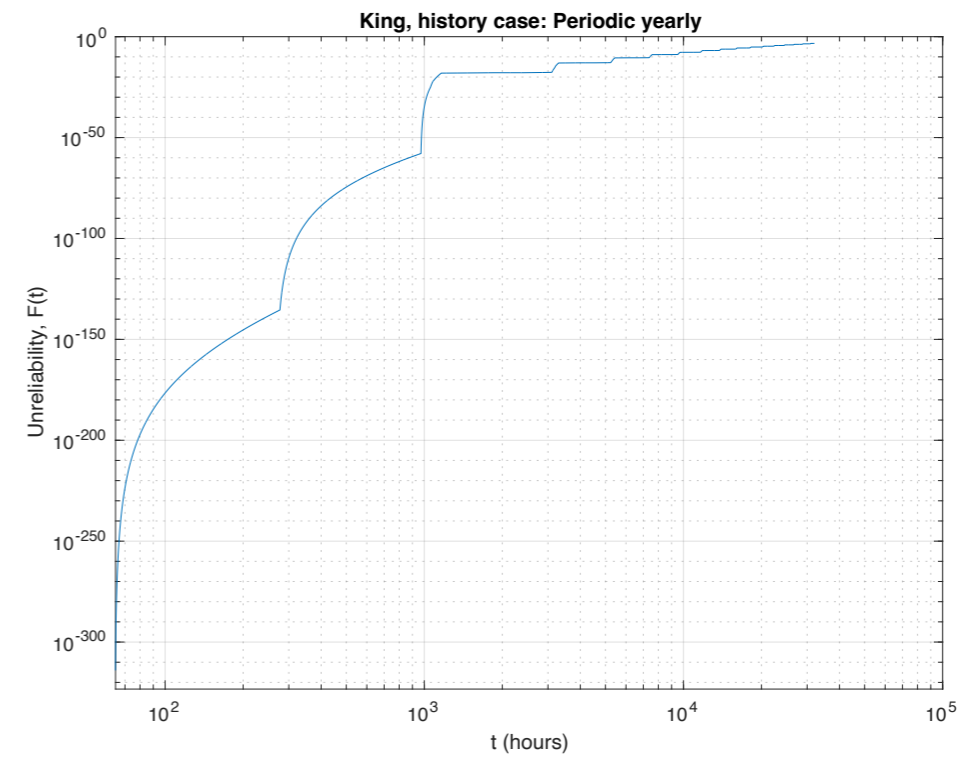
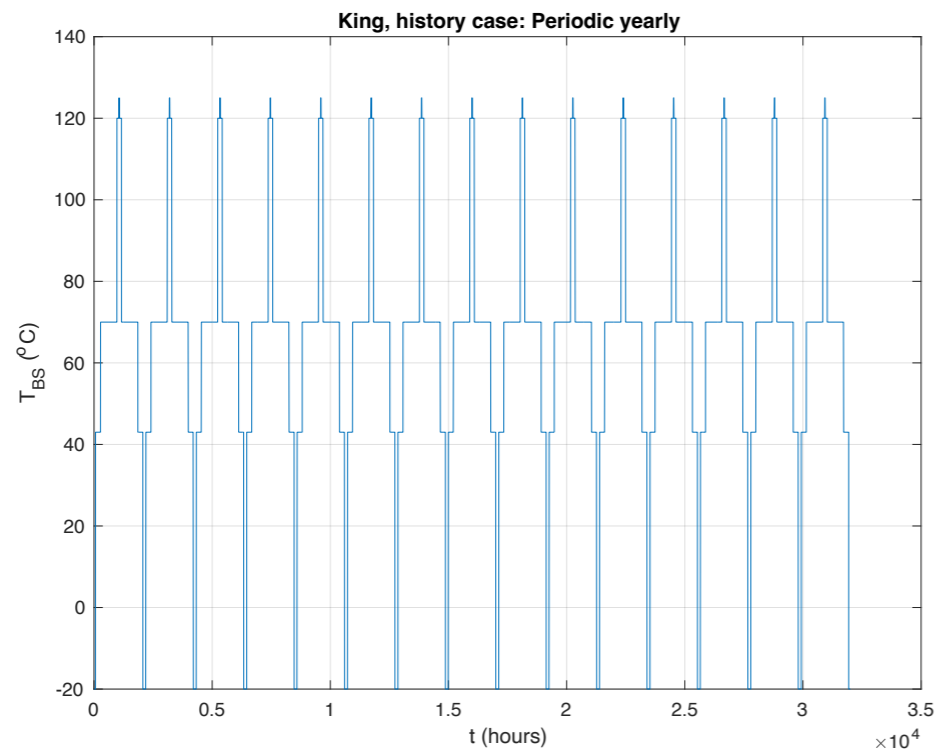


# Failures as function of $T_{BS}(t)$ : hot to cold

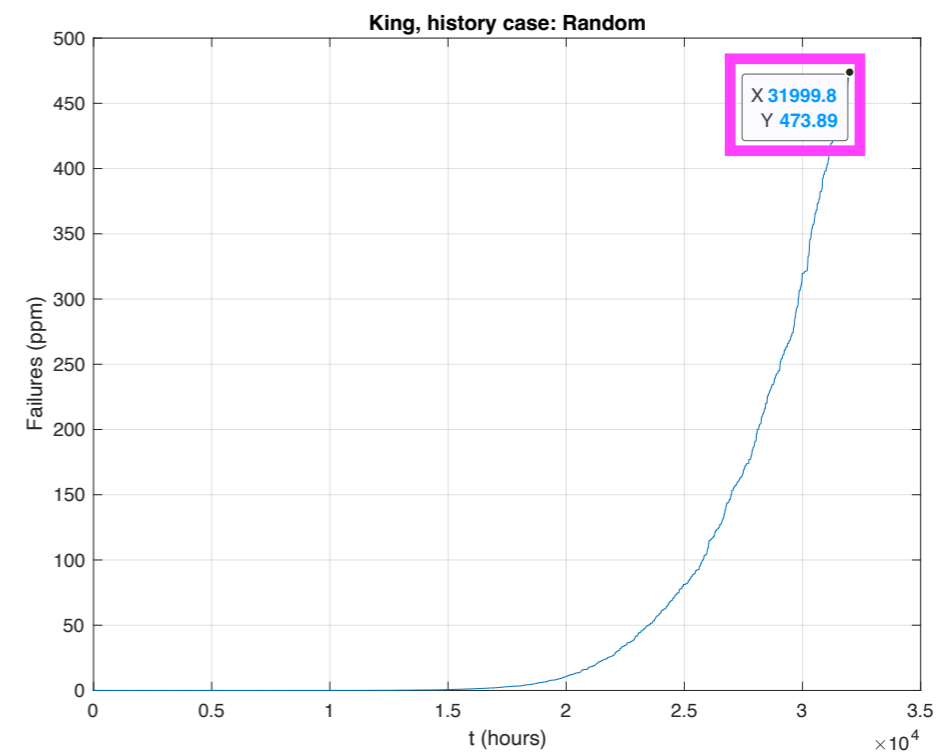
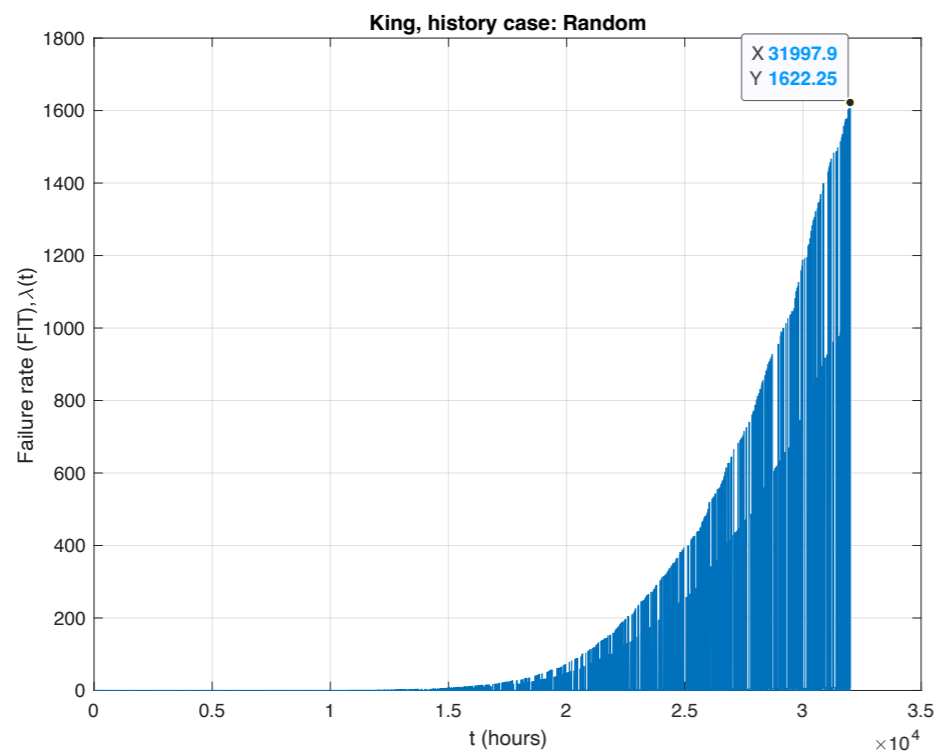
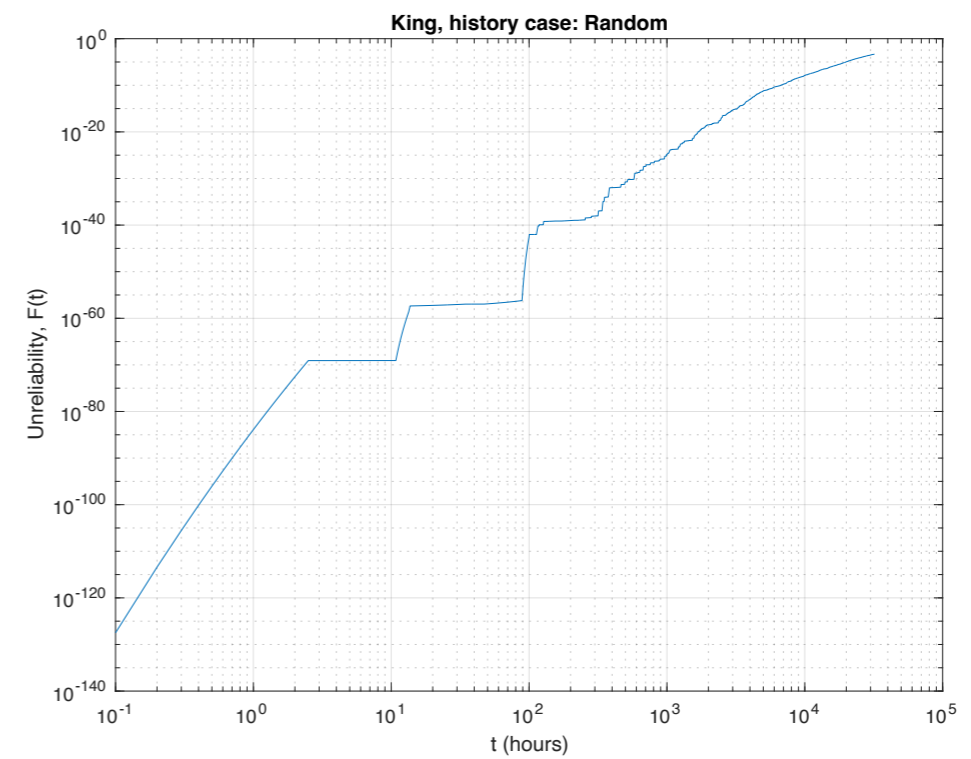
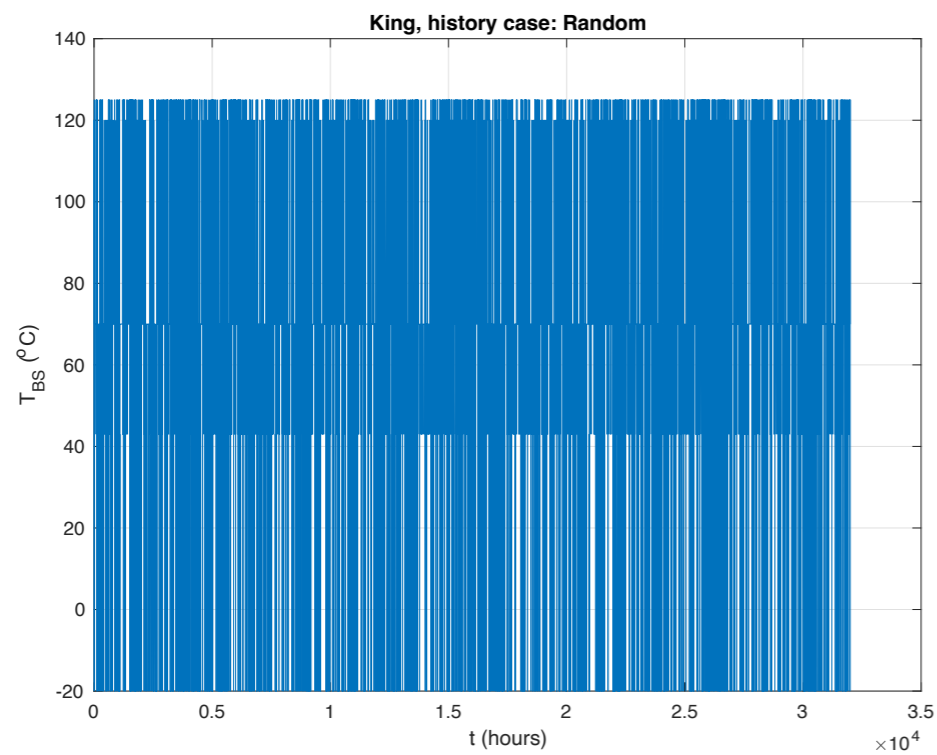




# Failures as function of $T_{BS}(t)$ : periodic yearly



# Failures as function of $T_{BS}(t)$ : random





# Reliability of 850nm VCSEL

Data presented in **giovane\_3cz\_01\_080621**

Model fitting and calculations presented in **perezaranda\_3cz\_01b\_080621\_vcsel\_reliability** and **perezaranda\_3cz\_01\_150621\_vcsel\_reliability\_annex**

# Reliability results



Reliability parameters

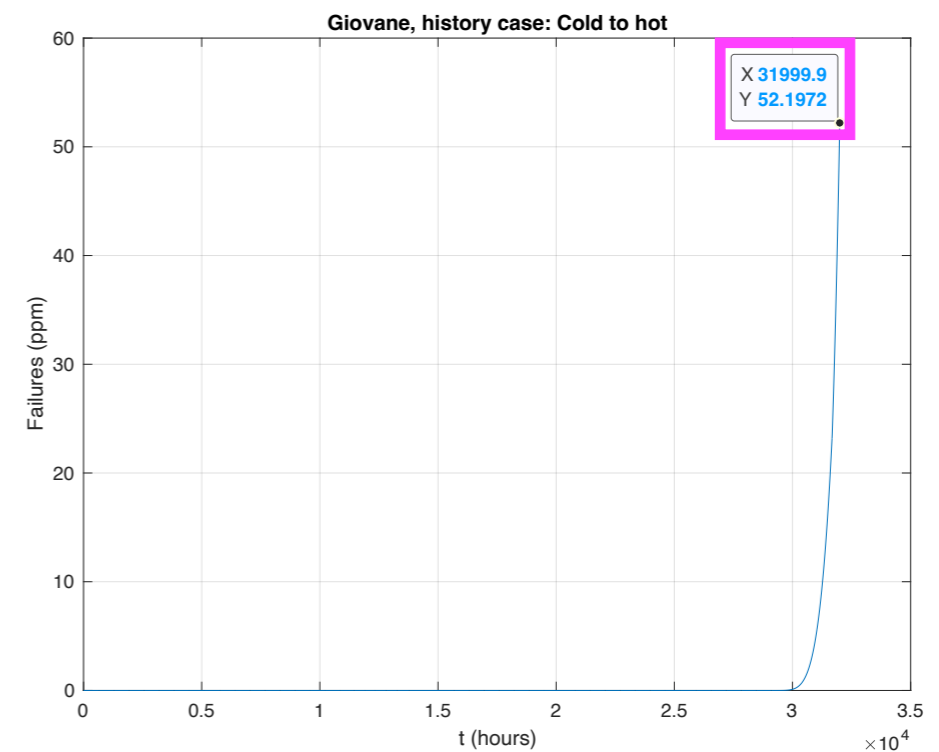
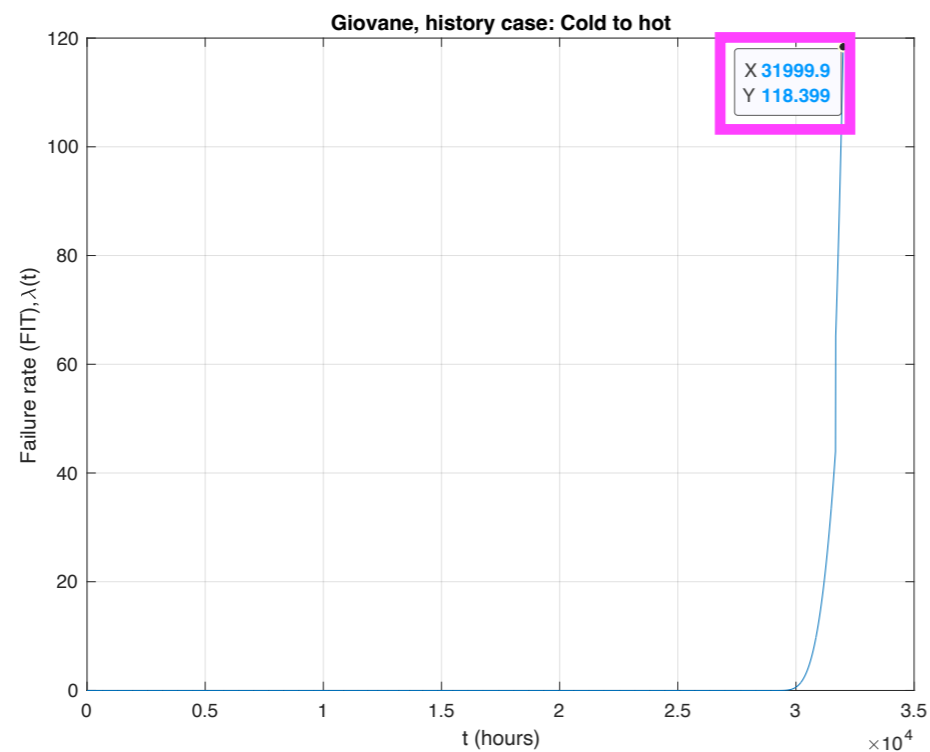
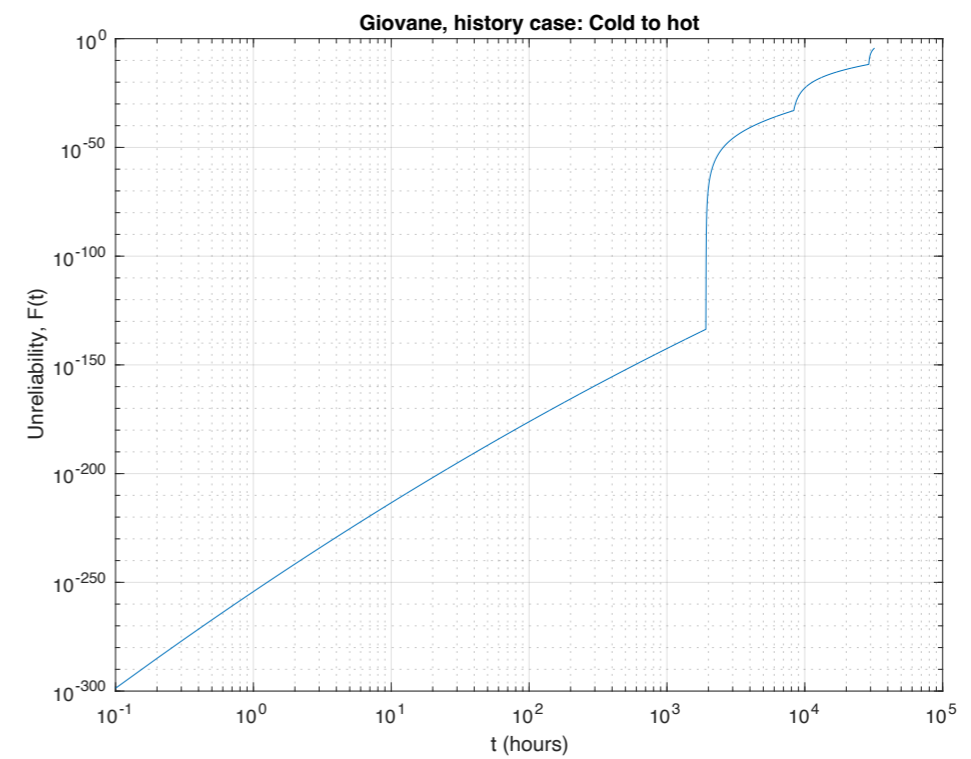
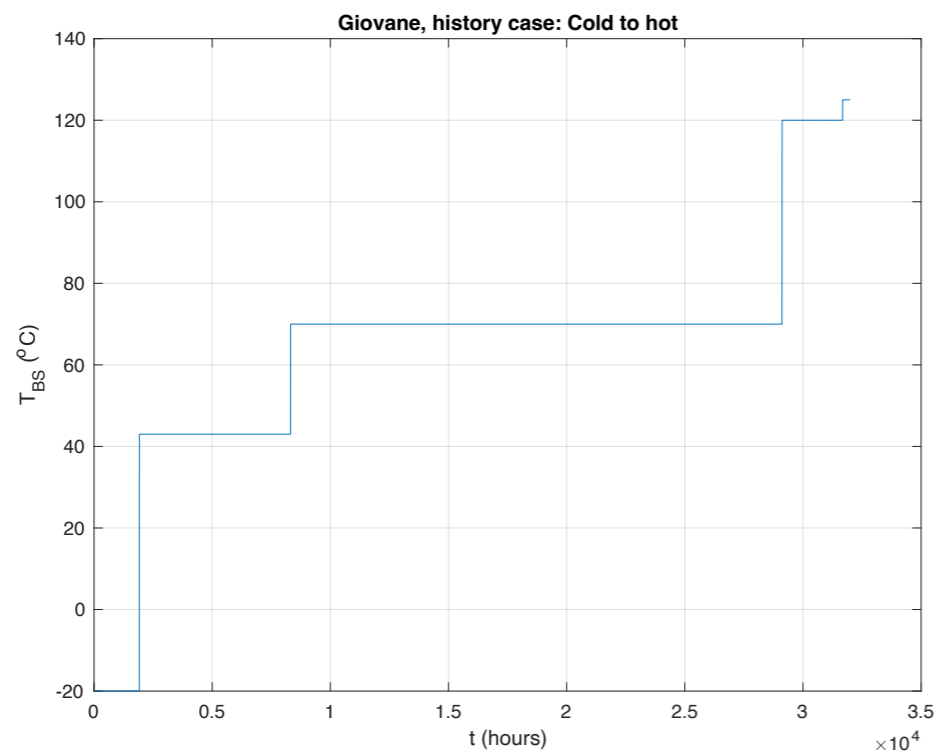
Operation			Reliability model	Wear out Ea (eV) @ T <sub>J</sub>	
Operation total time (h)	32000			1.150	Ea
Service life (years)	15			8.210	n can take any value w/o effect because reference I <sub>0</sub> = I <sub>OP</sub>
I <sub>OP</sub> (mA) max	7.5000			1.0	TTF for 1%
ΔT <sub>AS</sub> (°C)	20.00			0.8	σ' calculated from TTF <sub>50%</sub> and TTF <sub>1%</sub>
				7.5	I <sub>0</sub> = I <sub>OP</sub> = 7.5 mA
VCSEL model fitting			T <sub>10</sub> (°C)		
ΔT <sub>SJ</sub> (°C) @ 7.5mA	25.0		95.0	TTF <sub>1%</sub> ~100 years for 70°C substrate	
I <sub>FIT</sub> (mA)	7.5		873600		
			2.413444E-03	C = TTF <sub>x%</sub> · I <sub>0</sub> <sup>n</sup> · exp(-E <sub>a</sub> · e / (k <sub>B</sub> · T <sub>J0</sub> ))	
			1.6022E-19		
			1.3806E-23		
			1.1605E+04		
			273.15		

$$T_J = T_S + \frac{I_{BIAS} (mA)}{7.5} \cdot \Delta T_{SJ@7.5mA}$$

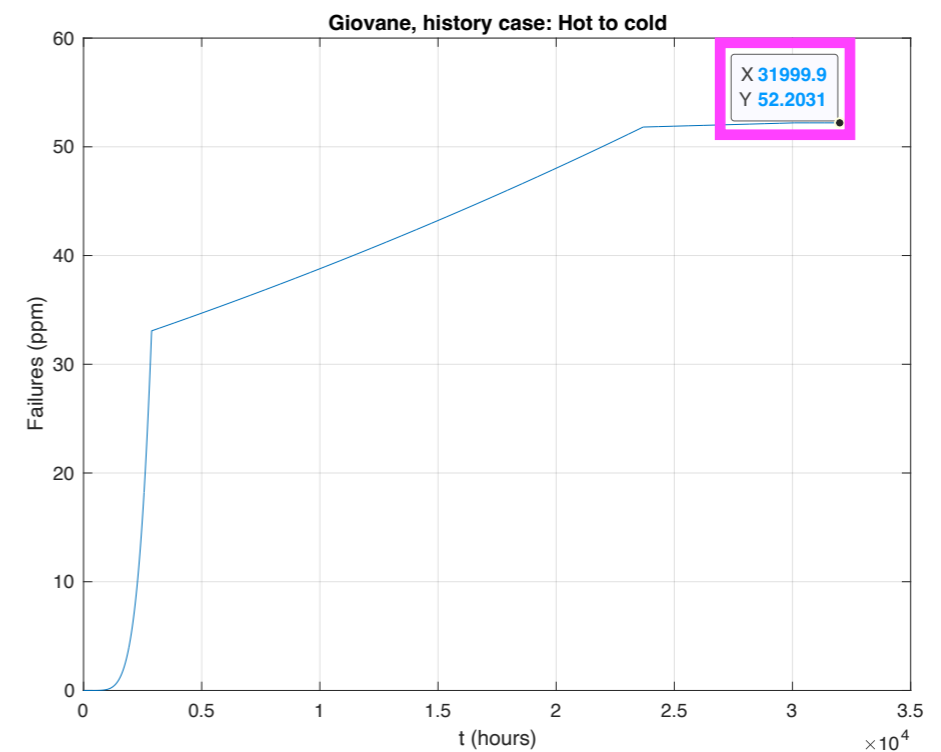
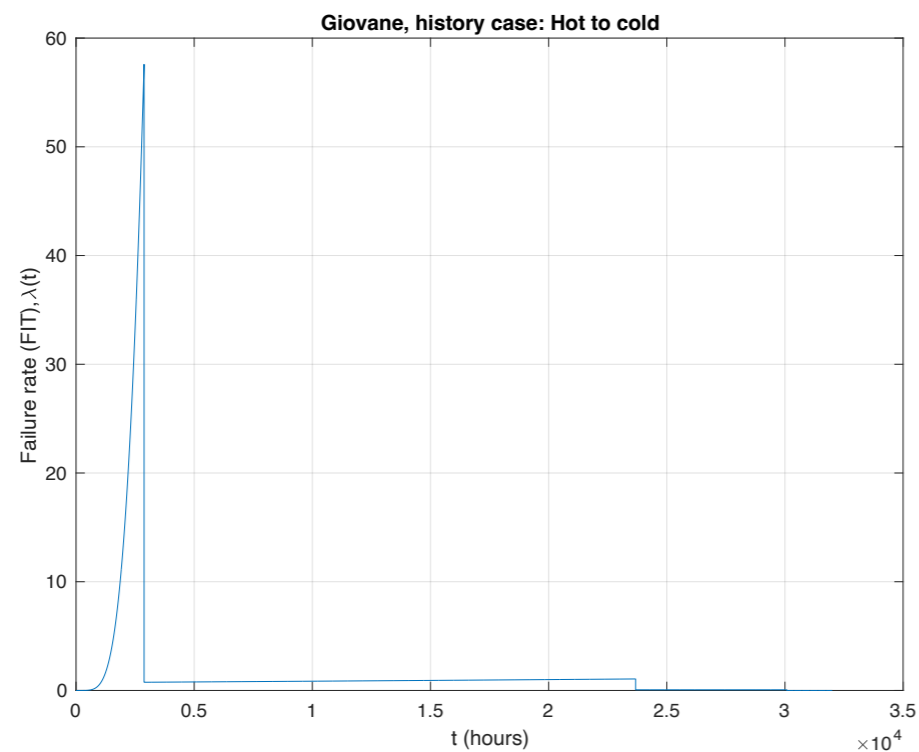
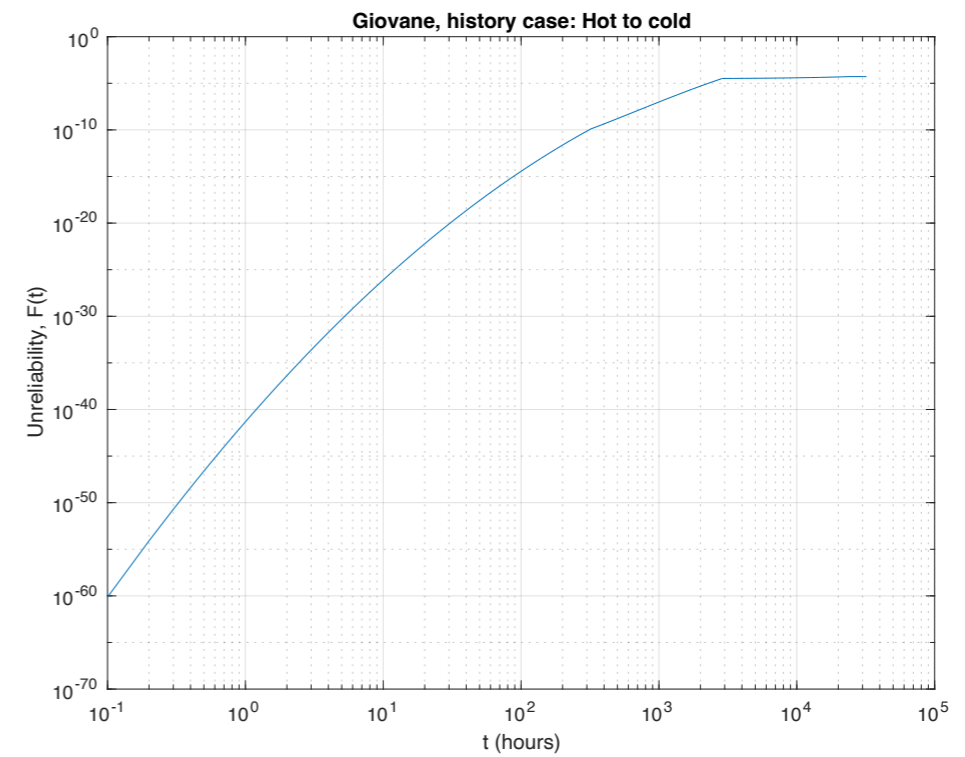
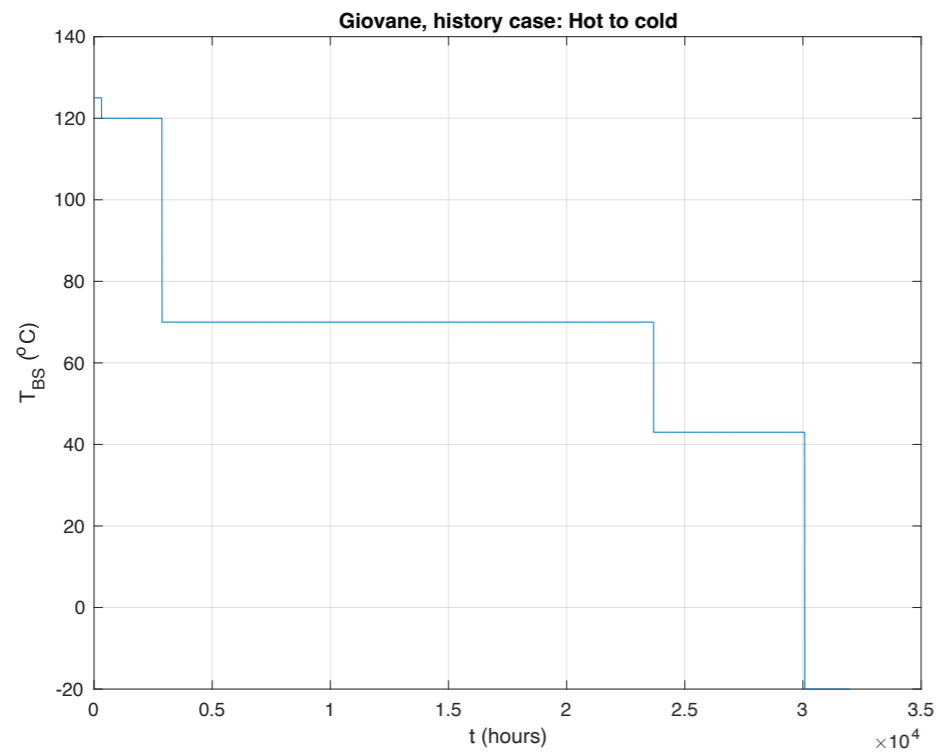
Reliability result

	Temperature profile				Failure rate				
	Percentage	Operation time per Temperature (h)	T <sub>A</sub> (°C)	T <sub>S</sub> (°C)	T <sub>J</sub> (°C)	TTF x% (hours)	Equivalent time in max T (hours)	Log-normal mu', ln (hours)	Failure-rate wear out (FIT)
T0	6 %	1920	-40	-20.00	5.0	1.084E+11	0.00	27.2706	
T1	20 %	6400	23	43.00	68.0	1.539E+07	3.27	18.4104	
T2	65 %	20800	50	70.00	95.0	8.736E+05	187.00	15.5415	
T3	8 %	2560	100	120.00	145.0	1.145E+04	1755.75	11.2070	
T4	1 %	320	105	125.00	150.0	7.854E+03	320.00	10.8298	
Cummulative	100 %	32000					2266.01	10.8298	118.4411

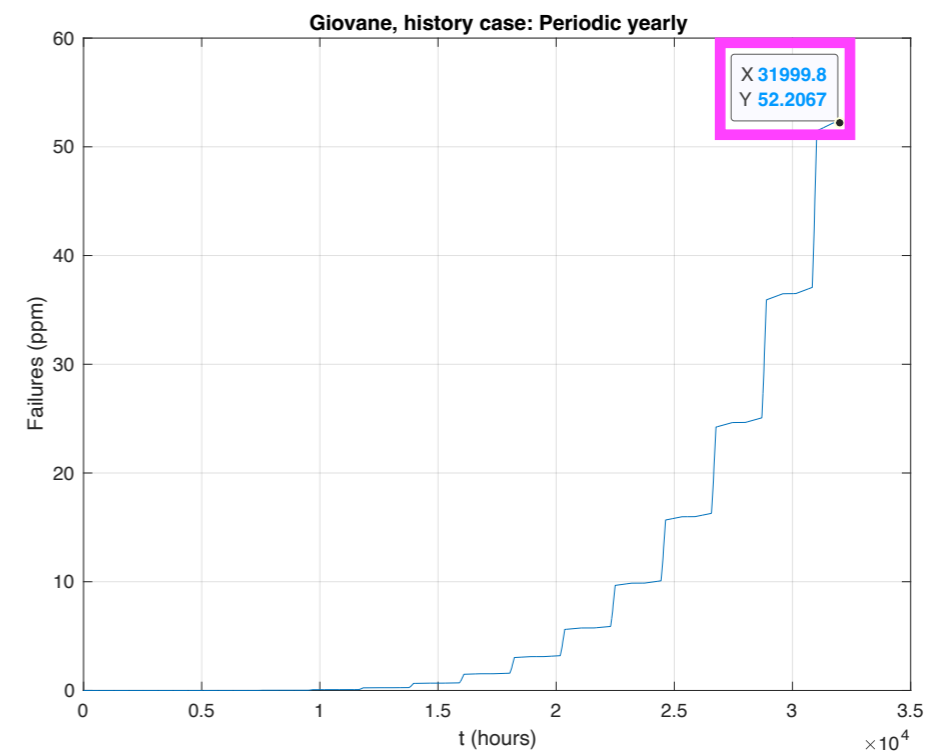
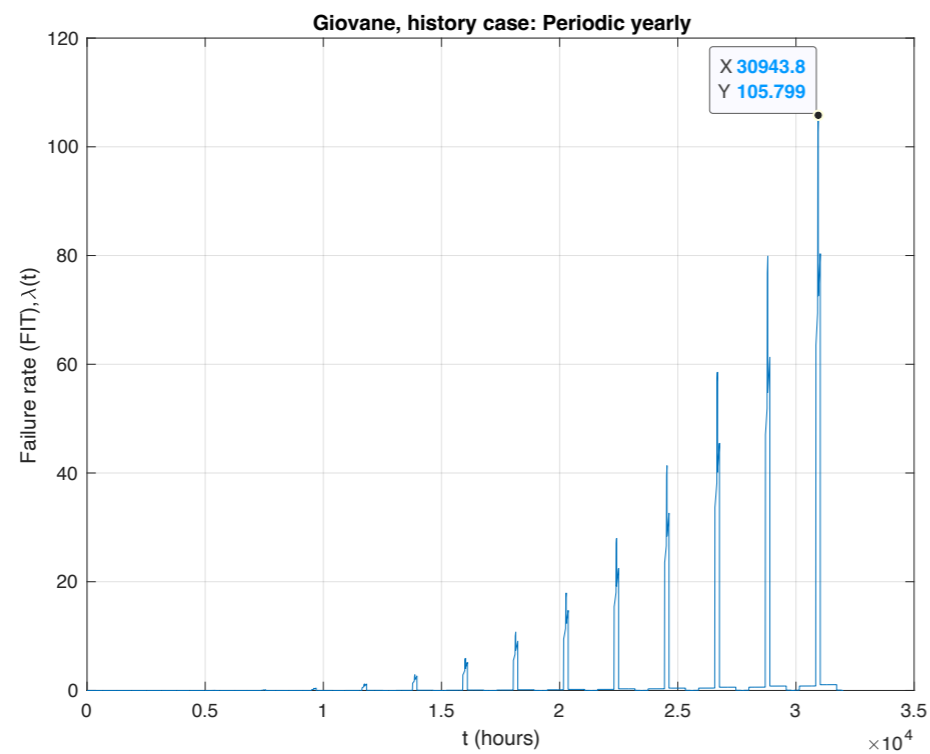
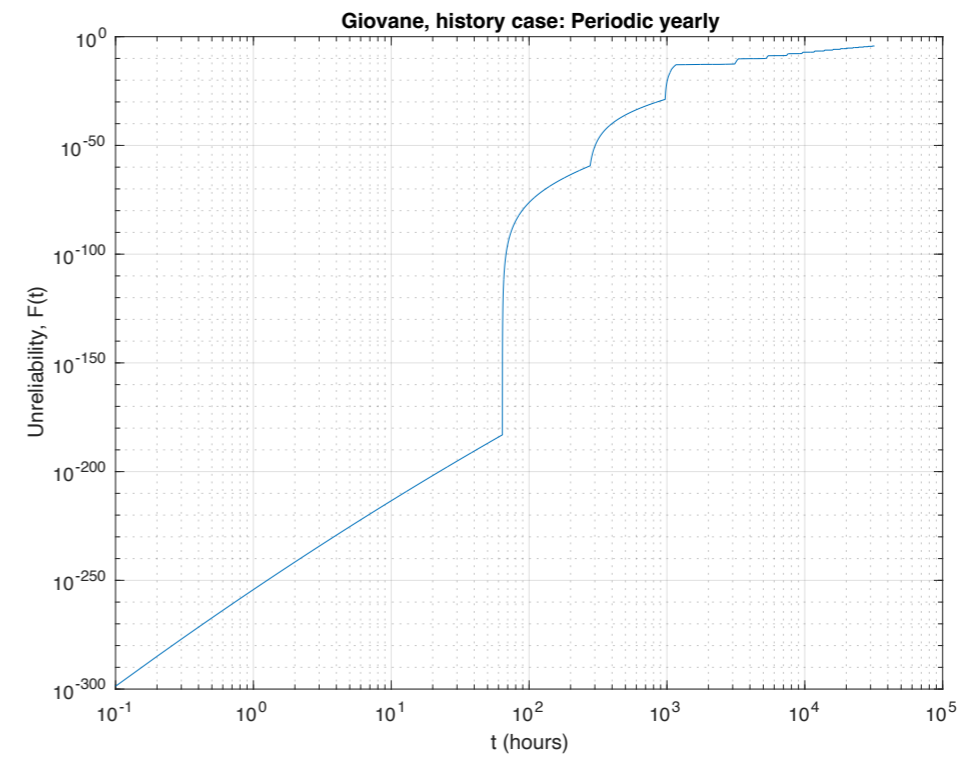
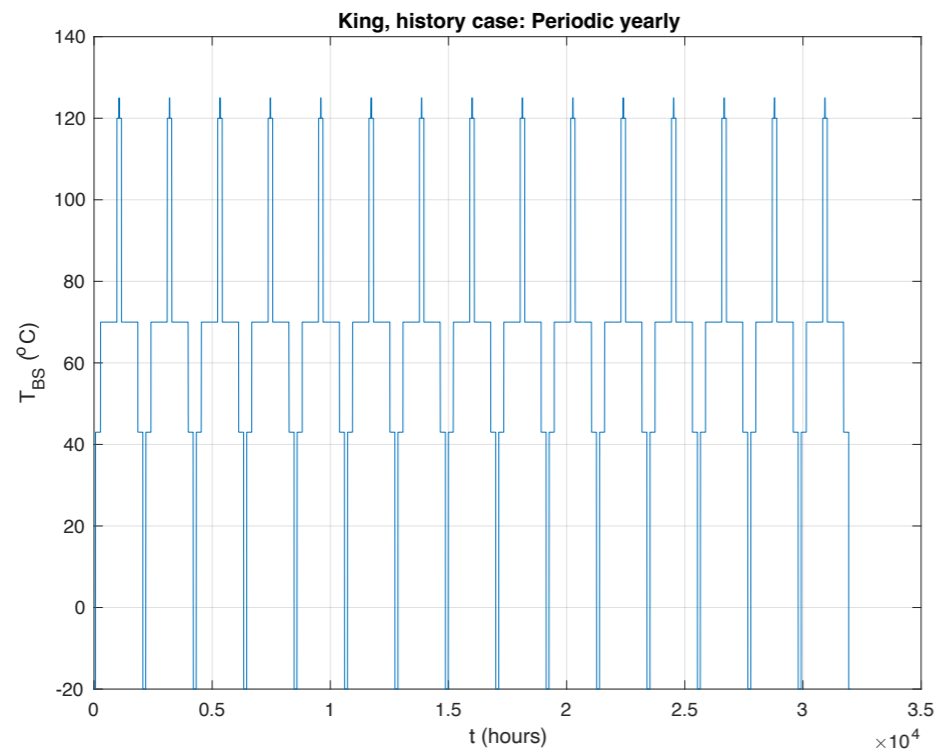
# Failures as function of $T_{BS}(t)$ : cold to hot



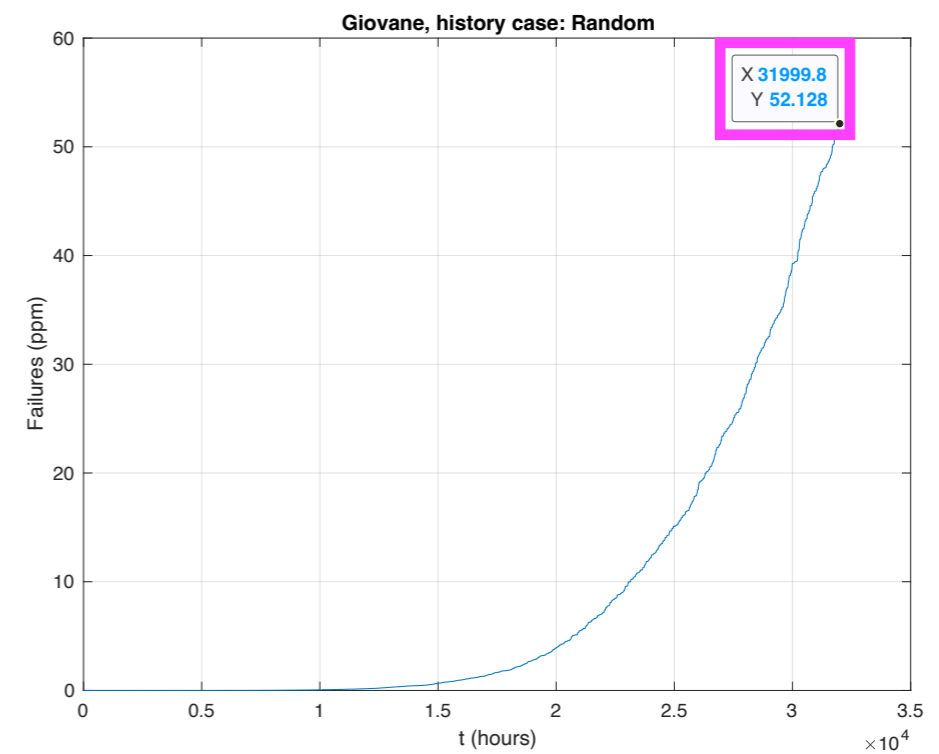
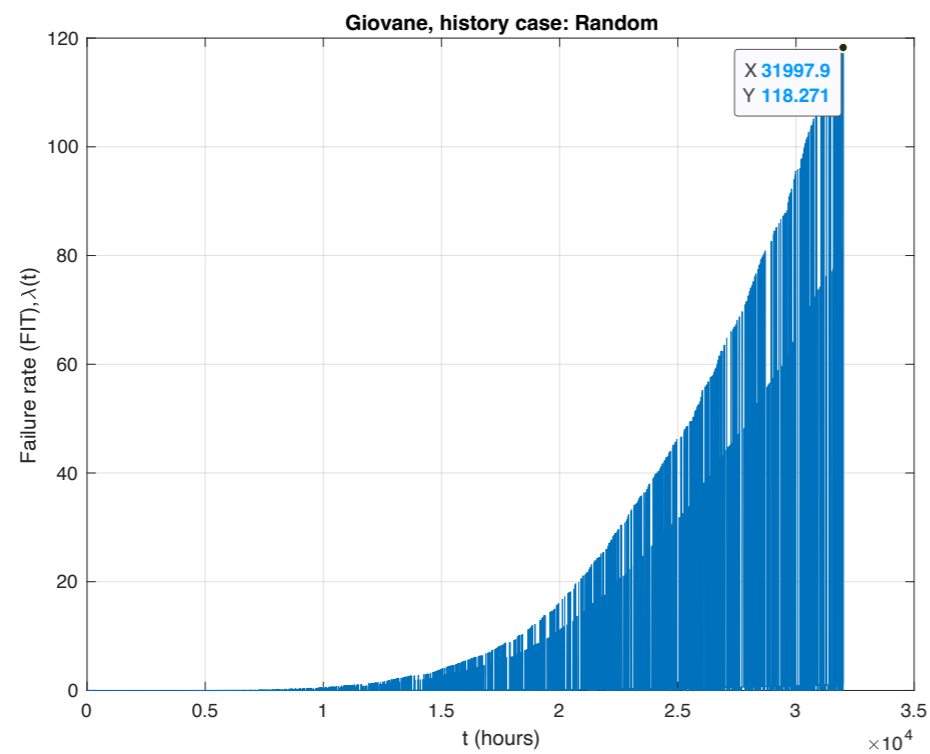
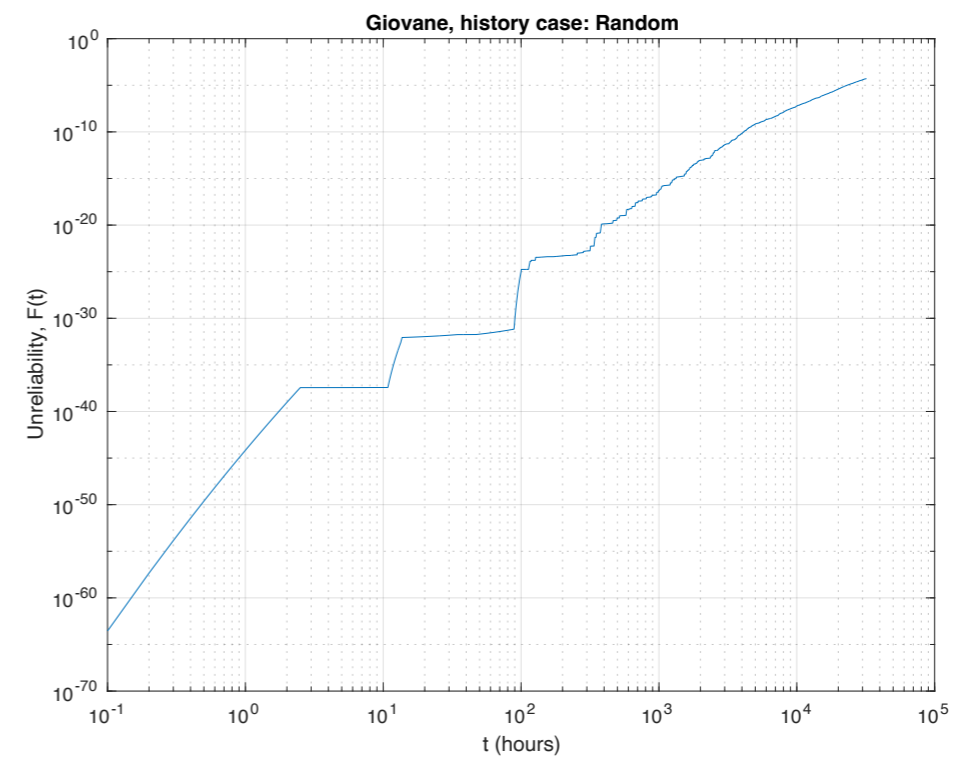
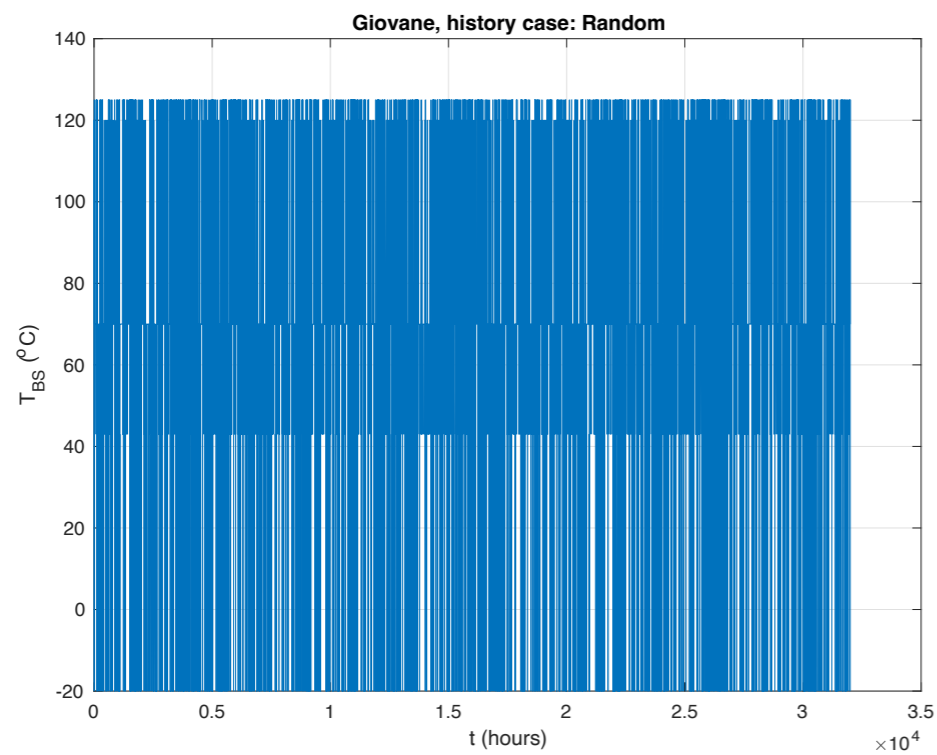
# Failures as function of $T_{BS}(t)$ : hot to cold



# Failures as function of $T_{BS}(t)$ : periodic yearly



# Failures as function of $T_{BS}(t)$ : random







# Reliability of 850nm VCSEL

Data and model presented in **Hoser\_3dh\_220824**

# Reliability results



## Reliability parameters

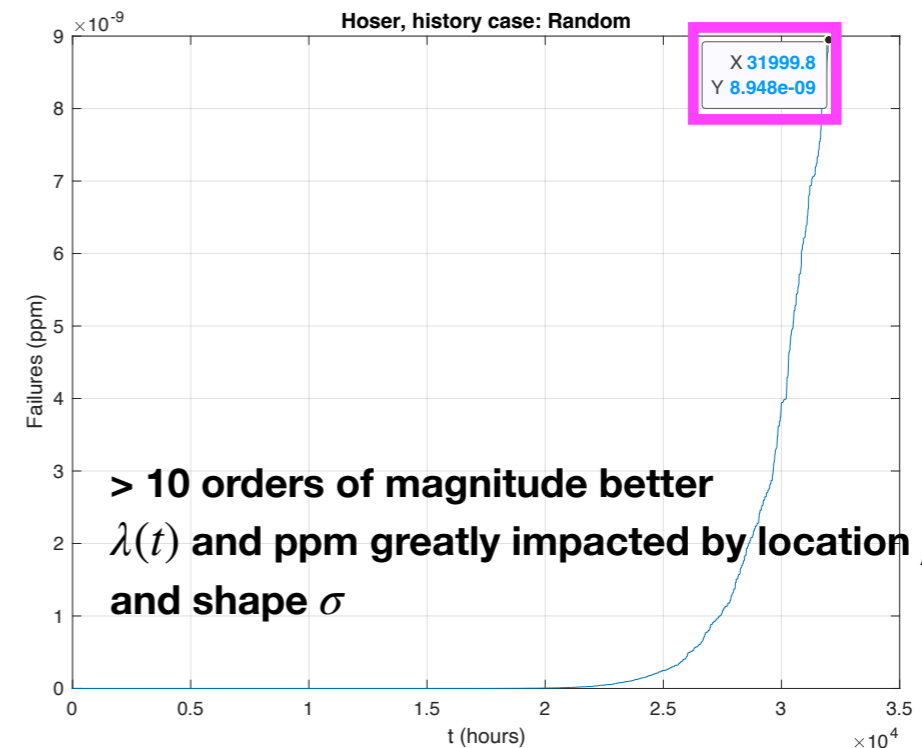
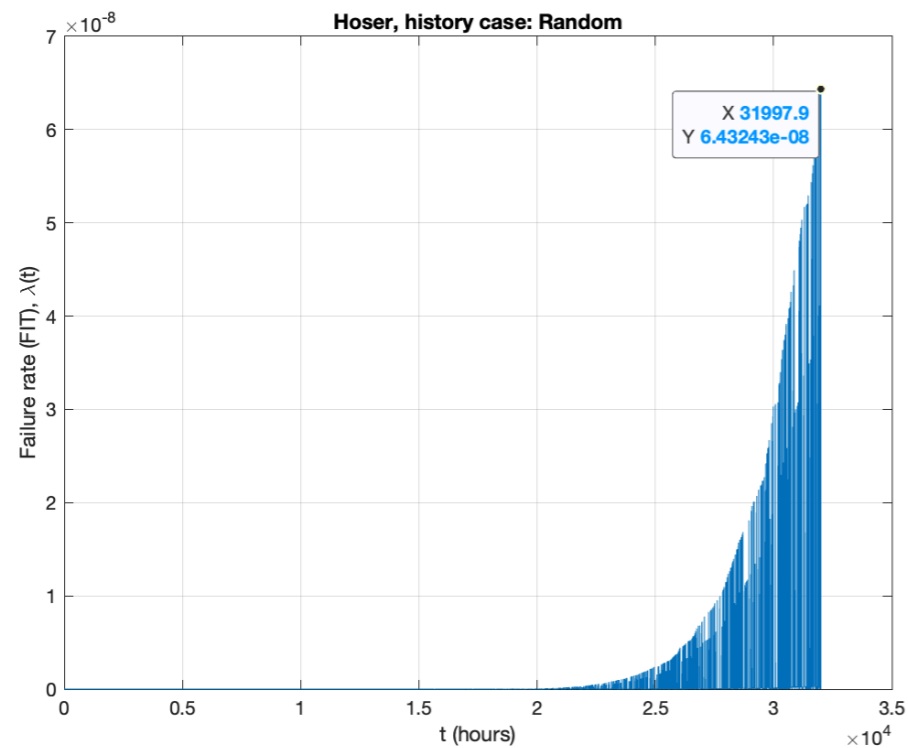
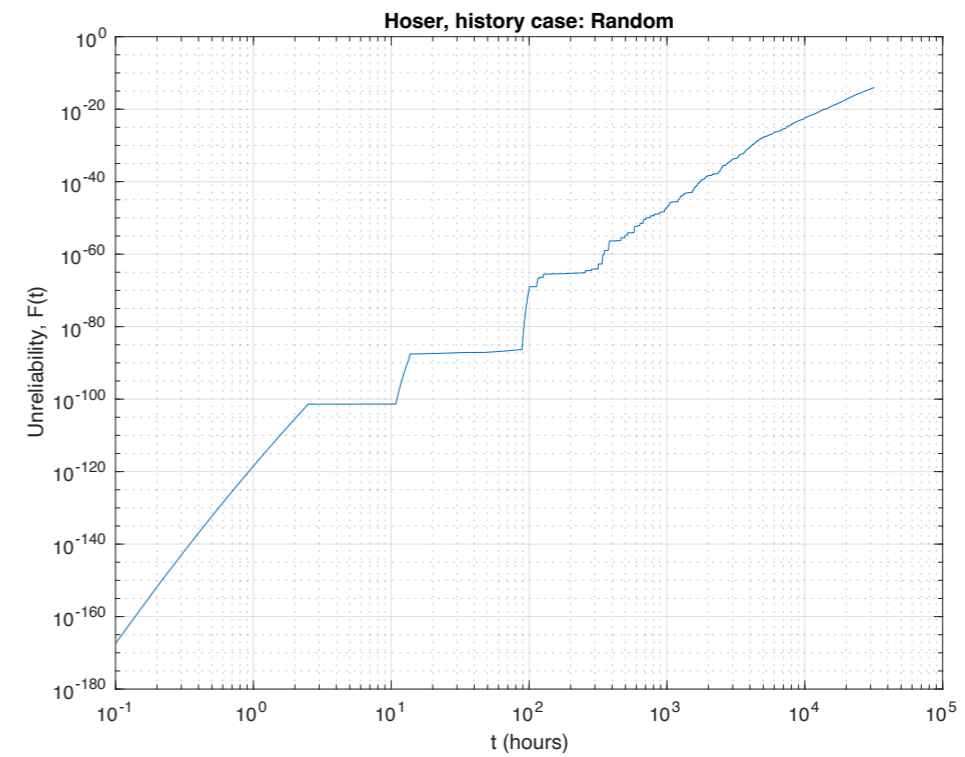
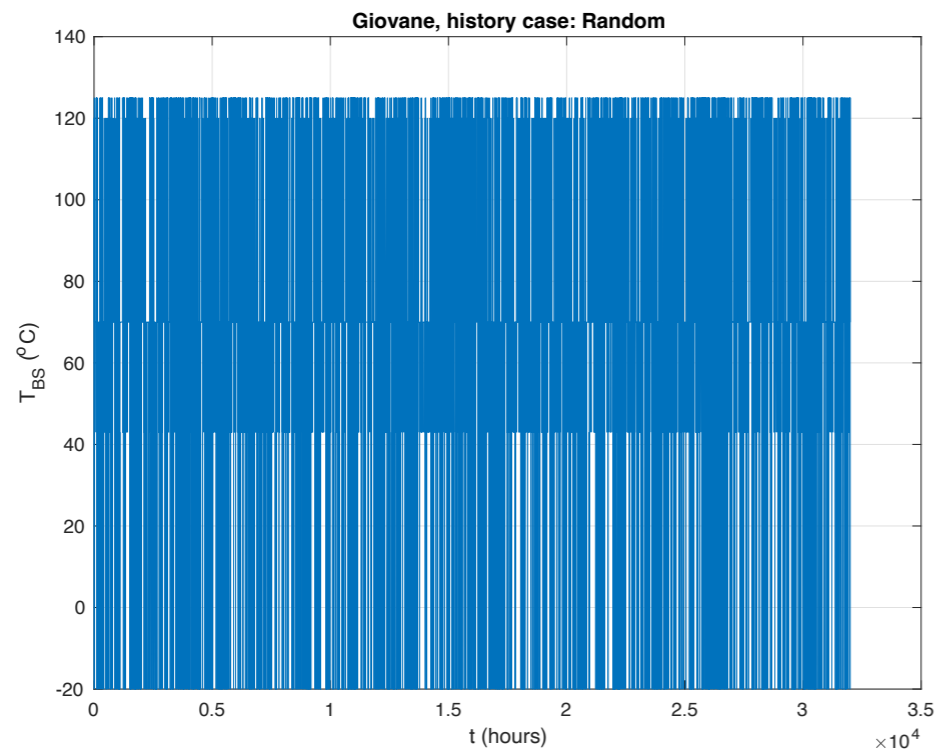
Operation	Operation total time (h)	32000	Reliability model	Wear out Ea (eV) @ Ts	1.15
	Service life (years)	15		Wear out n @ Ts	9.8
	I <sub>OP</sub> (mA)	7.0000		TTF x%, location	1.0
	ΔT <sub>AS</sub> (°C)	20.0		Log-normal σ', ln (hours)	0.52
				I <sub>0</sub> (mA)	7.00
				T <sub>S0</sub> (°C)	125
				TTF <sub>0</sub> x% (hours)	33383
				Arrhenius C factor (hours) @ T <sub>s</sub>	1.546241E-02
				Q <sub>e</sub>	1.6022E-19
				K <sub>B</sub>	1.3806E-23
			Q <sub>e</sub> /K <sub>B</sub>	1.1605E+04	
			°C to Kelvin	273.15	

## Reliability result

	Temperature profile				Failure rate			
	Percentage	Operation time per Temperature (h)	T <sub>A</sub> (°C)	T <sub>S</sub> (°C)	TTF x% (hours)	Equivalent time in max T (hours)	Log-normal mu', ln (hours)	Failure-rate wear out (FIT)
T0	6 %	1920	-40	-20.0	7.861E+12	0.00	30.9047	
T1	20 %	6400	23	43.0	2.063E+08	1.04	20.3567	
T2	65 %	20800	50	70.0	7.349E+06	94.49	17.0218	
T4	8 %	2560	100	120.0	5.122E+04	1668.61	12.0556	
T5	1 %	320	105	125.0	3.338E+04	320.00	11.6276	
Cummulative	100 %	32000				2084.13	11.6276	0.0

**Requirement is met!?**

# Failures as function of $T_{BS}(t)$ : random



**> 10 orders of magnitude better**  
 $\lambda(t)$  and ppm greatly impacted by location  $\mu$  for each  $T_{BS}$   
 and shape  $\sigma$



Thank you