A New Equation to Calculate Accelerated Life Test Temperature

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6.2.6.1.2 Accelerated Life Test

- The accelerated life test mentioned in section 6.2.6.1.2. evaluates the long-term performance of TPRDs

- It specifically targets the thermal creep of eutectic materials, commonly used as the triggering mechanism, under long term exposure to worst case temperatures driven by the environment or the application

- Procedure: The inlet ports of eight TPRDs are pressurized to 125% of NWP for 500 hours while exposed to the temperature calculated from $T_{life} = 9.1 \times T_{act}^{0.503}$

Issues Raised by Comments

- Issues with the current equation ($T_{life} = 9.1 \times T_{act}^{0.503}$):

  - Unbalance dimensions of the equation sides
    - Left hand side: T
    - Right hand side: $T^{0.503}$

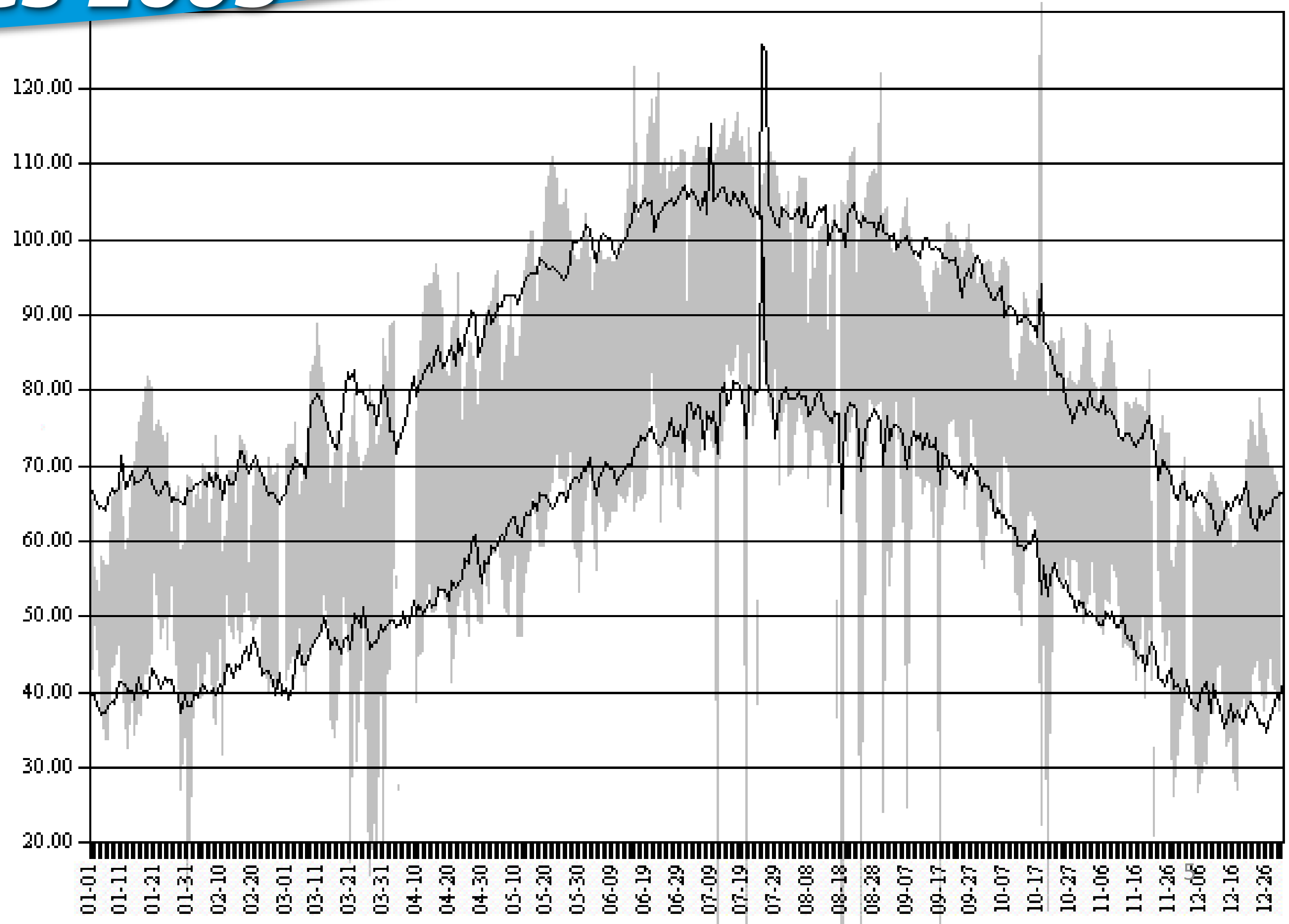
  - The equation only works for Celsius temperature scale
    - The equation cannot be used for Fahrenheit scale

Issues Found in Derivation of the Current Equation

- Constitutive equation:
  - $t = A \times T^B$ based on an assumption
    t is time
    T is temperature
    A is constant
  - T is in relative scales (C/F) instead of absolute scales (K/R)
- Temperatures and durations:
  - Temperature and duration values needs more careful review and probably more experiments for validation and improvement especially for fast fill (Latest experiment: 2006)

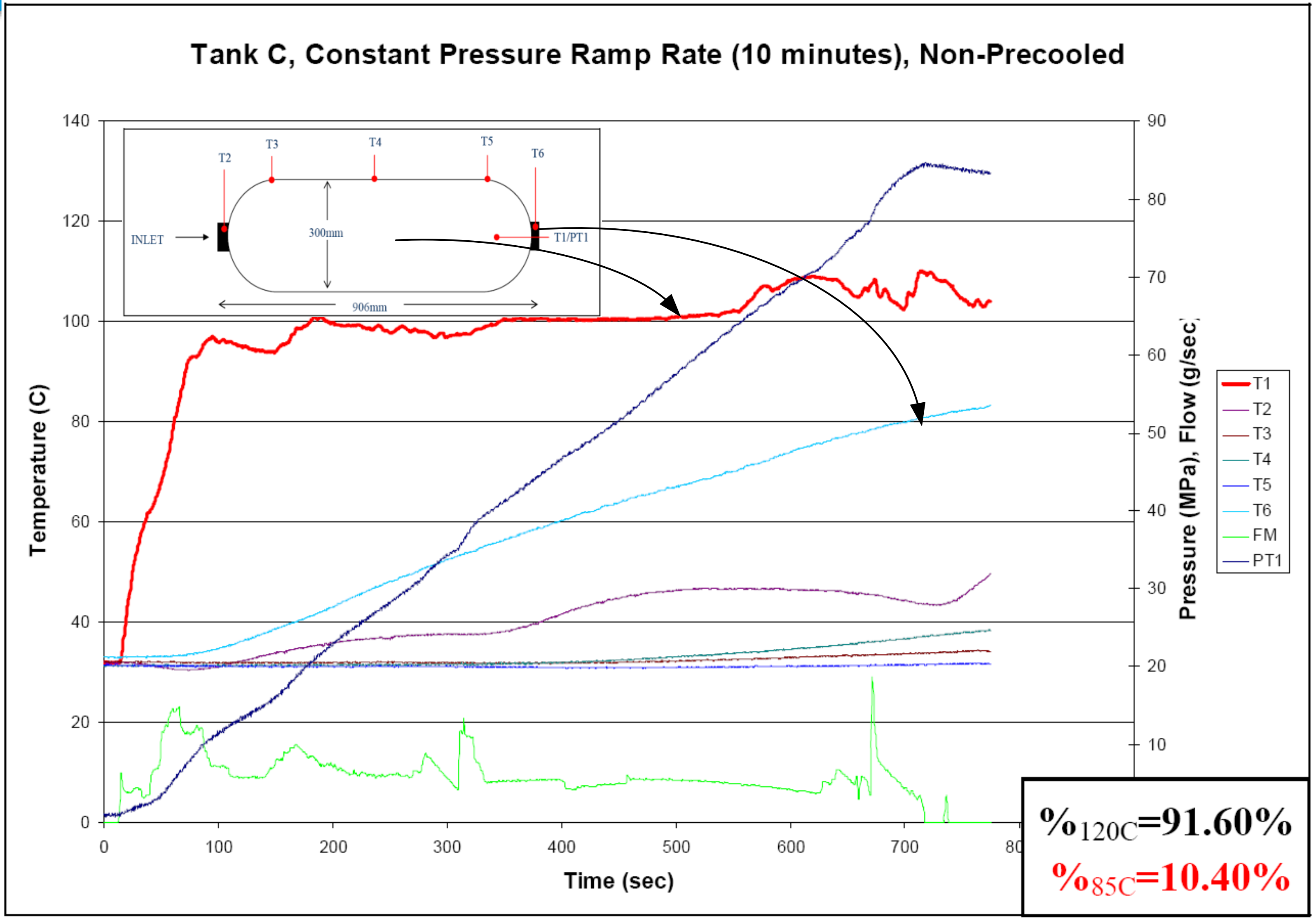
GM Desert Proving Ground-Mesa, AZ Daily Temperatures 2005

Environmental driven temperature



Experiment Results (Schneider et al 2006) For H2

Operational driven temperature



Worst Case Temperatures

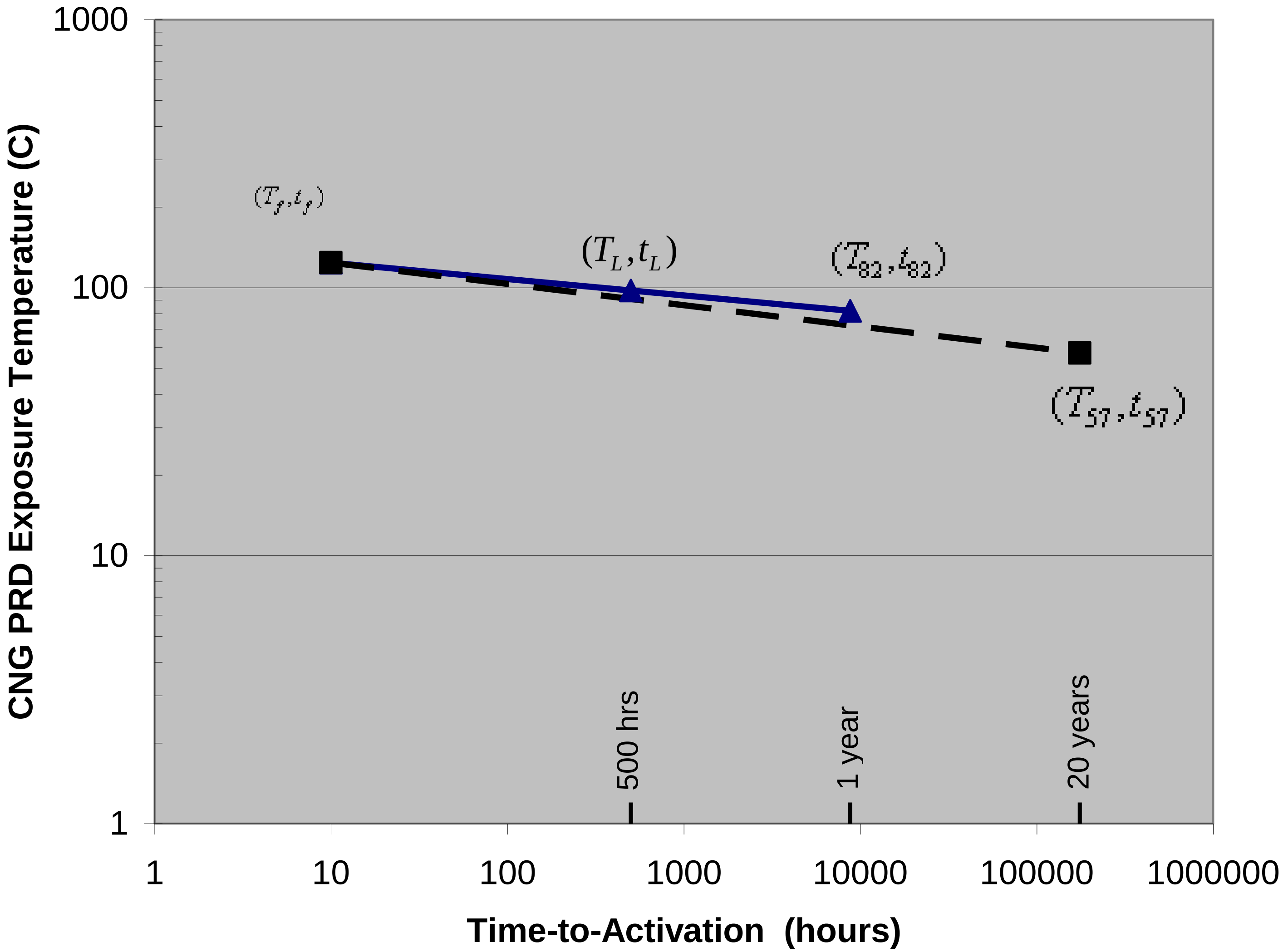
		CNG	H2
Life time		20 years (20,000 cycles)	**20 years (15,000 cycles) - 750 fill cycles per year, i.e. 2 per day**
Worst Case Ambient Temperature	Temperature	+57°C (+135°F) [GM 2003]	**+57°C (+135°F)**
	Time	Life time	**Life time**
Maximum Settled Gas Temperature after Fill	Temperature	+57°C (+135°F)	**+85°C (+185°F)**
	Time		**1 hour per fill cycle - i.e. up to 5% of life time (1 year)**
Max Fill Temperature shutoff	Temperature	Not applicable (not an upper level shutoff in the same manner as H2)	**+85°C (+185°F)**
Maximum Transient Gas Temperature During Fill	Temperature	+90°C (+194°F)	**+120°C (+248°F)**
	Time		**10 min at each refill - 1 hour at 85C per fill cycle for compensation - i.e. up to 5% of life time (1 year) at 85C**
Environmentally driven Max Container and PRD Temperature	Temperature	+82°C (+180°F) (black car on black asphalt in Arizona summer)	**+85°C (+185°F) (A bit more conservative than)**
	Time	Up to 5% of life time (1 year)	**Up to 5% of life time (1 year) at 85C**

Summary of Temperatures and Durations

	CNG		Hydrogen	
	Temp (°C)	time	Temp (°C)	time
Long term	T_{57} = 57	t_{57} = 20 yrs	T_{57} = **57**	t_{57} = **20** yrs
Max temperature	T_{82} = 82	t_{82} = 1 yrs	T_{85} = **85**	t_{85} = **3** yrs
Activation temperature	T_f	t_f = 10 hrs	T_f	t_f = **10** hrs
Accelerated life temperature	T_L	t_L = 500 hrs	T_L	t_L = **500** hrs

Analysis to Calculate T_L

- "As shown in the figure, the slope of the line through is more shallow than the line through , implying that a PRD which meets the 82°C criterion will also meet the 57°C criterion. Accordingly, to demonstrate that a PRD meets the 82°C criteria we place the PRD under constant temperature T_L. The figure then illustrates that if the time-to-activation at long-term test temperature T_L, exceeds the minimum activation time, t_L, then the PRD should meet both our 82°C and 57°C long-term performance criteria."



Derivation of the New Equation_1

- Constitutive equation based on physics behind creep strain rate (Reference 2-4):

  $\dot{\gamma} = Bexp(-D/T)$, where

  $\dot{\gamma}$ is strain rate,

  B and D are material constants,

  T is temperature in absolute scale (K/R)

- Assumption: eutectic material creeps continuously with a constant rate at a constant temperature → $\dot{\gamma} = \gamma_{total}/t_{act}$, where

  γ_{total} is total strain to activation

  t_{act} is time to activation (hereafter shown as t)

- γ_{total} is constant → $t_{act} = Cexp(A/T)$ → $\log(t/C) = A/T$, where A and C are constants

Summary of Temperatures and Durations

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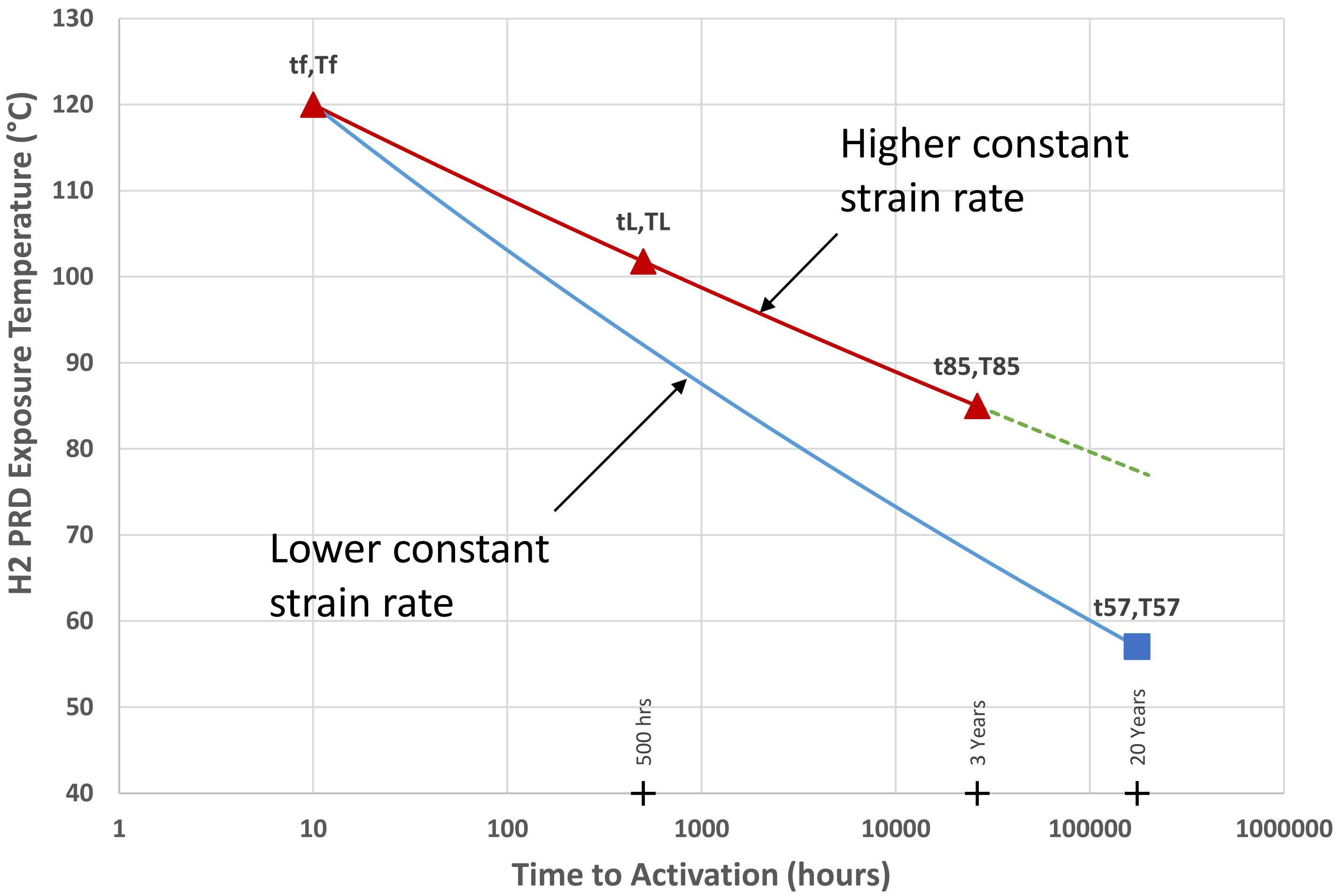
Accelerated life temperature	T_L	t_L = 500 hrs	T_L	t_L = **500** hrs

Derivation of the New Equation_2

- Assumption: If the PRD can stand a higher strain rate (higher temperature) after 500 hours, it will not activate at a lower strain rate at the end of its life time



Final Form of the Equation

- Substituting parameters from the table of Page 6:

$$\frac{1}{\beta + T_L} = \frac{1 + \alpha}{\beta + T_f} - \frac{\alpha}{\beta + T_{85}}$$

- Where

$$\alpha = \frac{\log(t_L/t_f)}{\log(t_f/t_{85})}$$

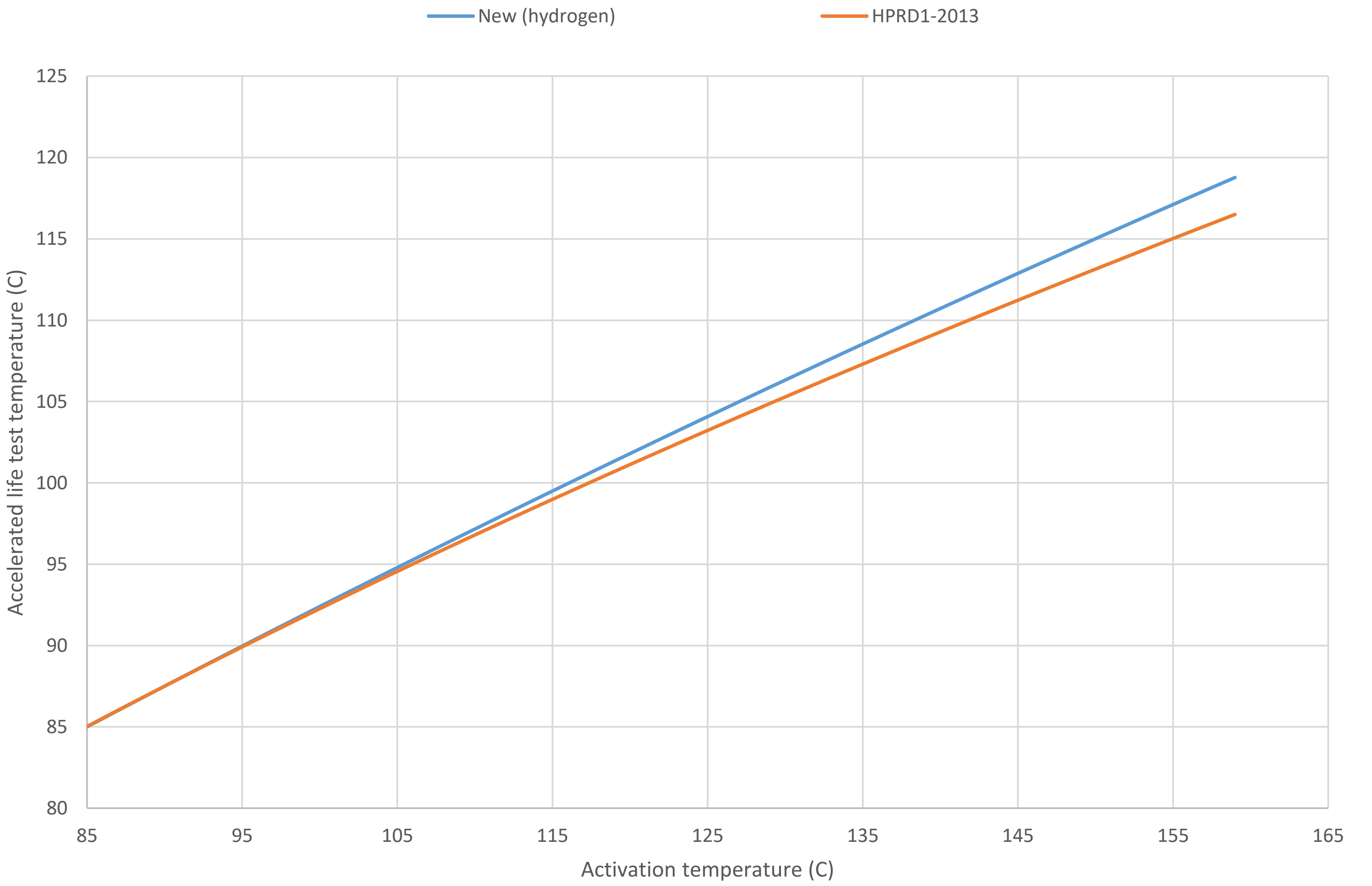
- And finally by substituting numerical values for hydrogen:

$$T_L = \left(\frac{0.502}{\beta + T_f} + \frac{0.498}{\beta + T_{85}}\right)^{-1} - \beta$$

Final form of the new equation

Where $\beta = 273.15$ if T is in Celsius and $\beta = 459.67$ if T is in Fahrenheit, $T_{85} = 85$C (185F), and T_f is the manufacturer's specified activation temperature

Results and Comparison



References

1. Rationale for Long-term Test Temperature for Thermally Activated PRDs, Denny R Stephens, 2006
2. J. Electronic Packaging, Transaction of ASME, Vol. 124, JUNE 2002, P. 85
3. Thermomechanical behaviour of solder joints in electronic packages. Master Thesis, van Houten, J.G.A., 1995
4. An Experimental Investigation of Creep and Viscoelastic Properties Using Depth-Sensing Indentation Techniques. Lucas, Barry Neal, PhD diss., University of Tennessee, 1997

Additional Information

$$\dot{\varepsilon}^{cr} = B\,\sigma^{n}\exp\left(-Q/RT\right) \qquad \textbf{(5.11)}$$

where ε^{cr} is the uniaxial creep strain, and σ is the uniaxial stress. The material parameters in eq. (5.10) and eq. (5.11) are listed in table 5.3 for three solder alloys. Govila et al. (1994) didn't provide material parameters. All solder alloys showed a temperature-dependent stress exponent n.

Investigator	Solder alloy	B [(sec·MPa^n)$^{-1}$]	Q [kJ/mol]	n (T [K]) [-]
Pao (1993a)	PbSn10	100.6	7.42	4.25(T=313) 3.03(T=413)
Pao (1993b)	SnCu3	$9.1014\cdot10^{-6}$	49.1	7.99(T=313) 6.30(T=413)
Sørensen (1994)	SnPb37	exp(25)	168	$4305T^{-1} - 4.6$

Table 5.3: Strain rate against stress at room temperature for the three solder alloys.

J. Electronic Packaging, Transaction of ASME, Vol. 124, JUNE 2002, P. 85