Experimental evaluation of the acceleration factors and activation energies for humidity-based degradation phenomena in c-Si modules

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How to perform Accelerated Life Testing ?

Experimental Set-up:

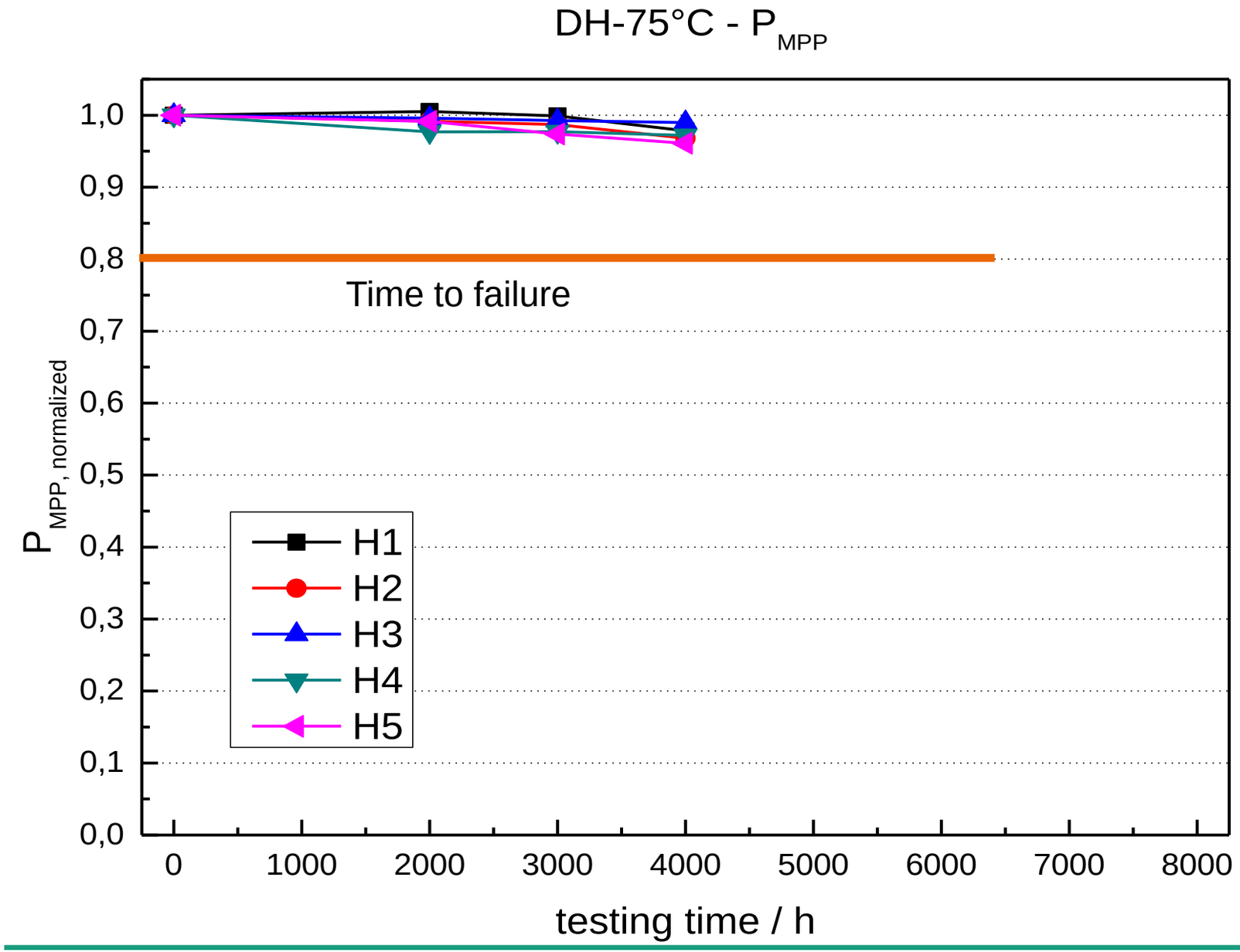
5 different commercially available c-Si module types in the framework of National German project „PV-Zuverlässigkeit II“)

Different constant load tests

- Damp-heat-UV
- Damp-heat-humidity-freeze
- Temperature cycling
- Combi-tests
- **Damp-heat tests**

Evaluation of the parameters for time-transformation functions by ALT

Damp-heat testing at 85%rh of 5 different c-Si modules at 75°C



After half year:

no significant changes

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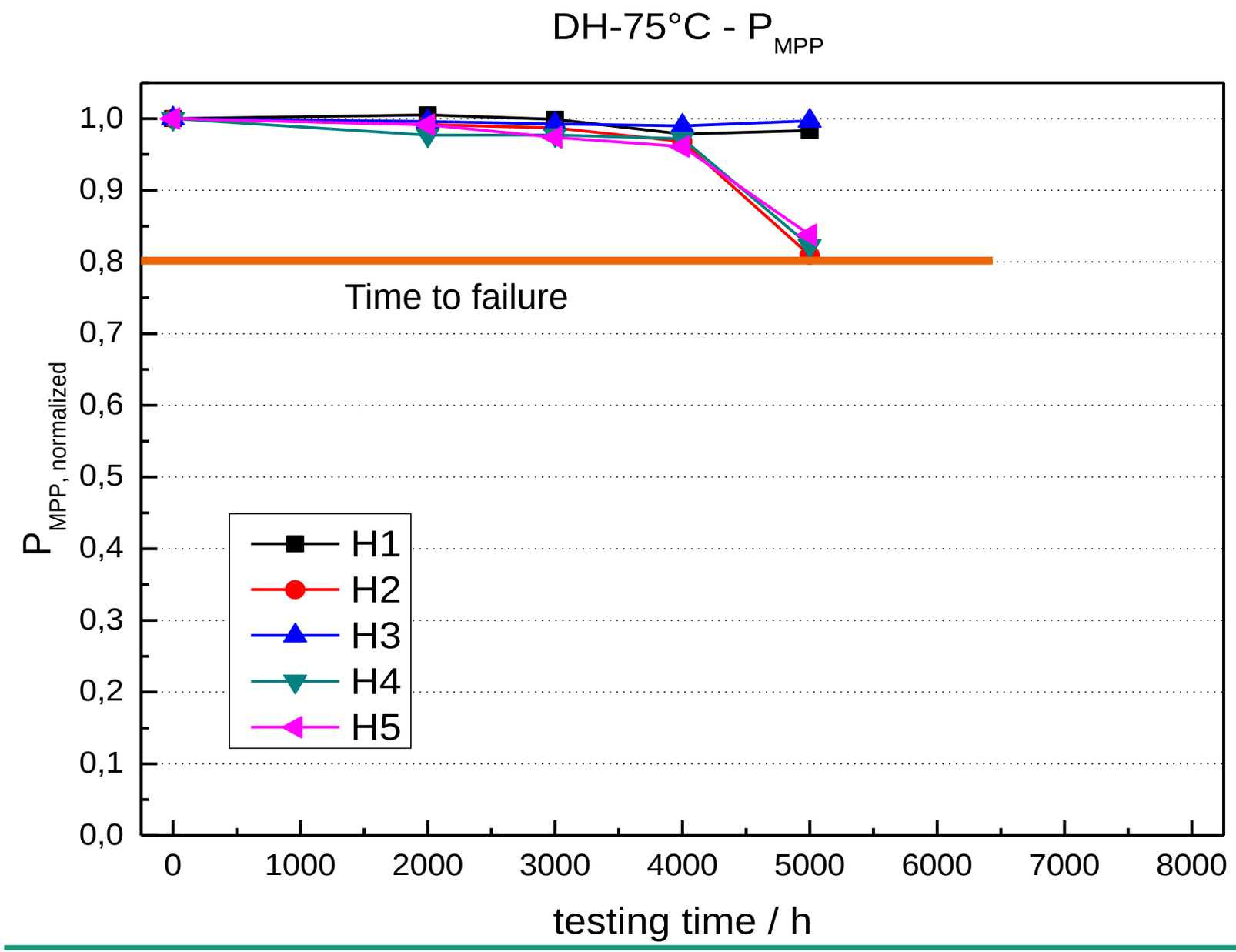

H1, H3 no changes

H2, H4, H5 similar time to failure

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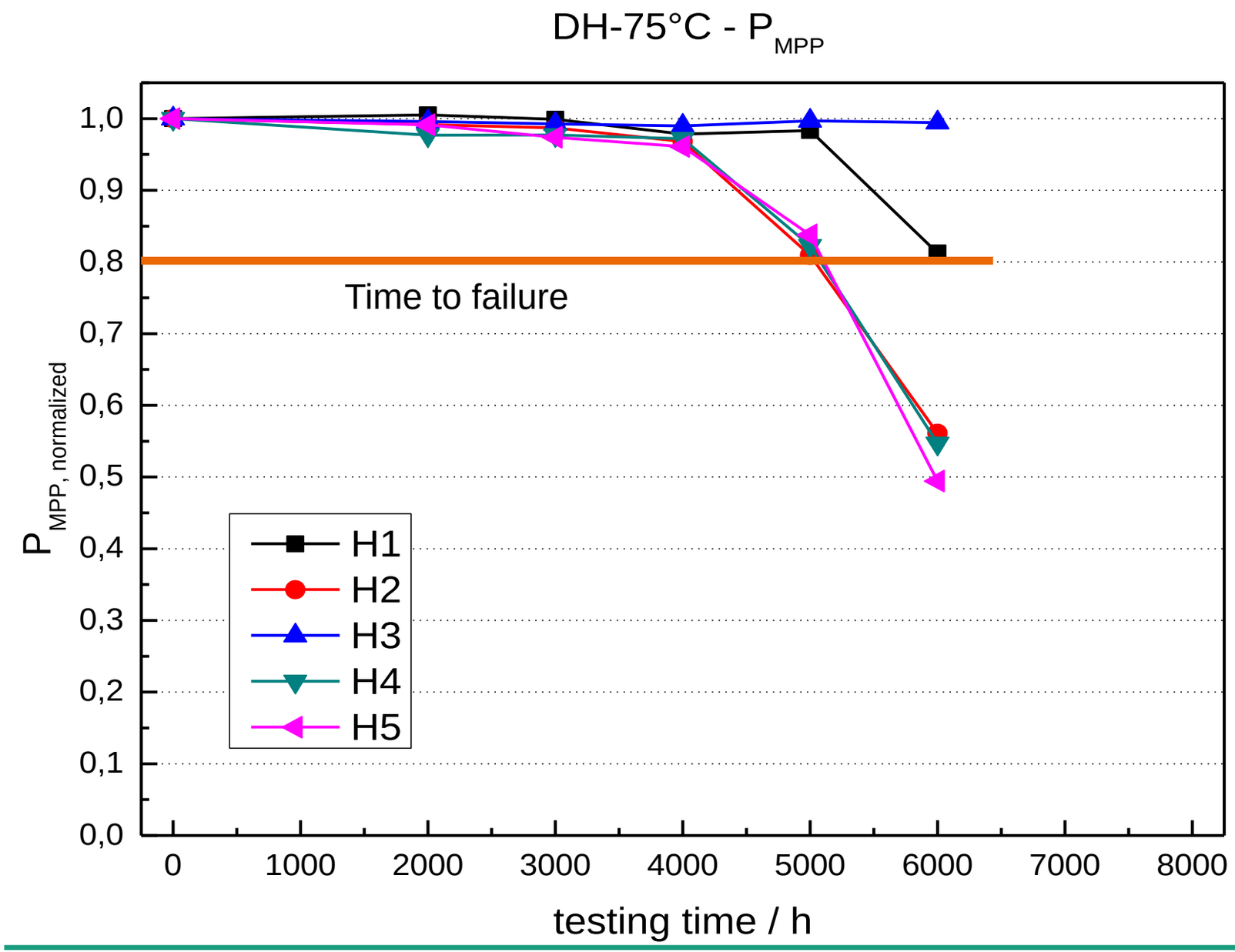

H3 no changes

H1 longer time to failure

H2, H4, H5 similar

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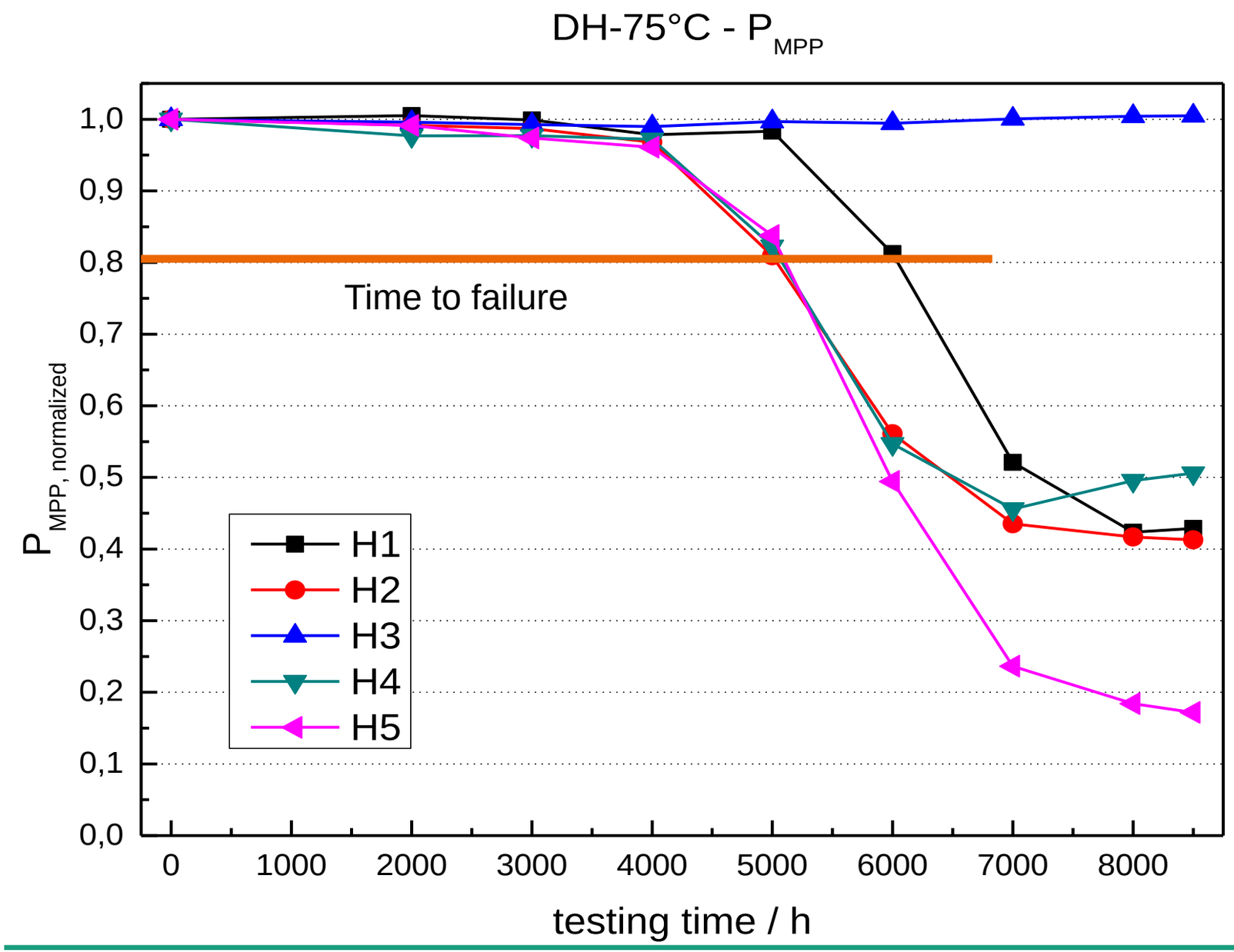

After one year:

H3 no changes

H1 longer time to failure

H1, H2, H4 similar end

H5 more degradation

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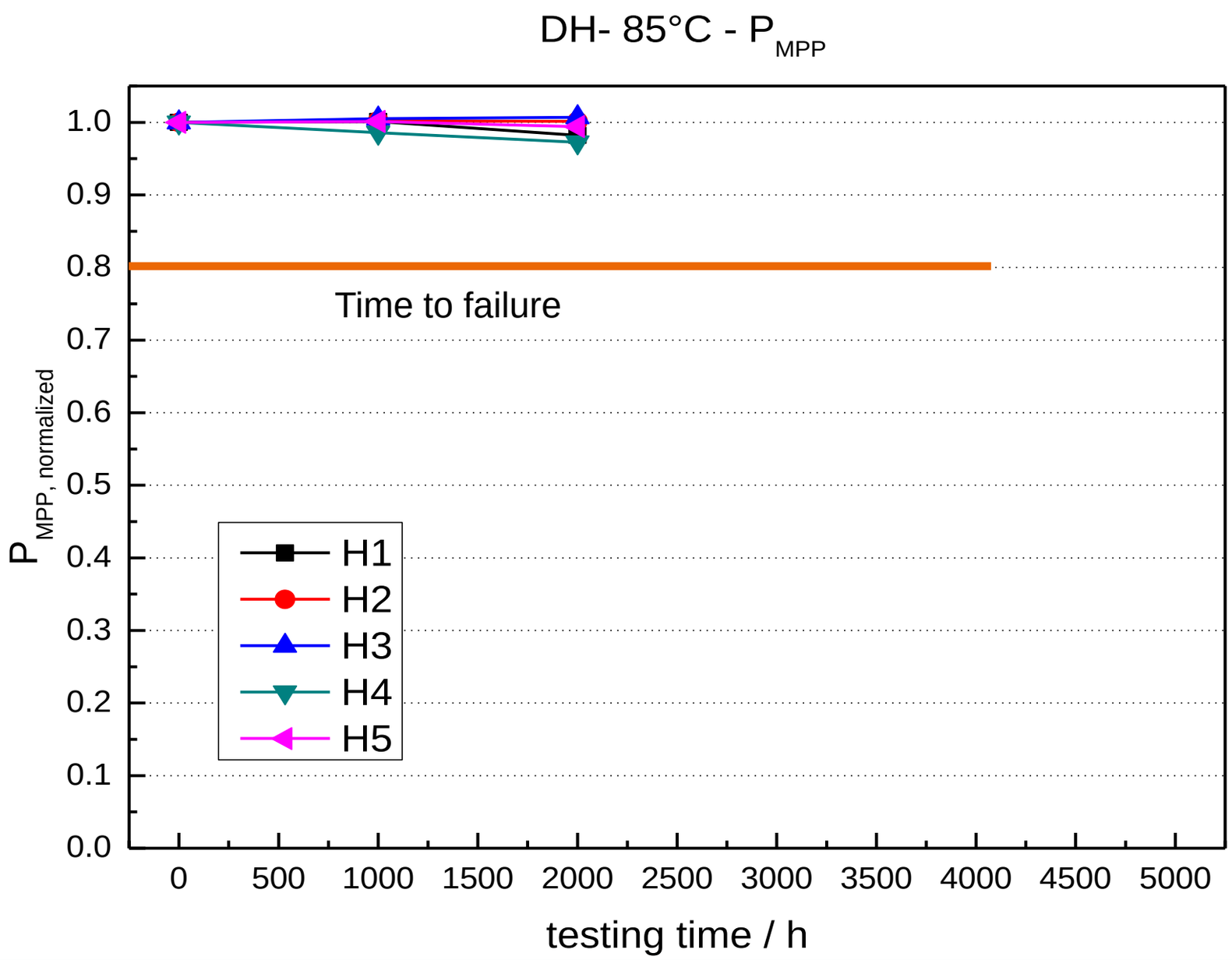

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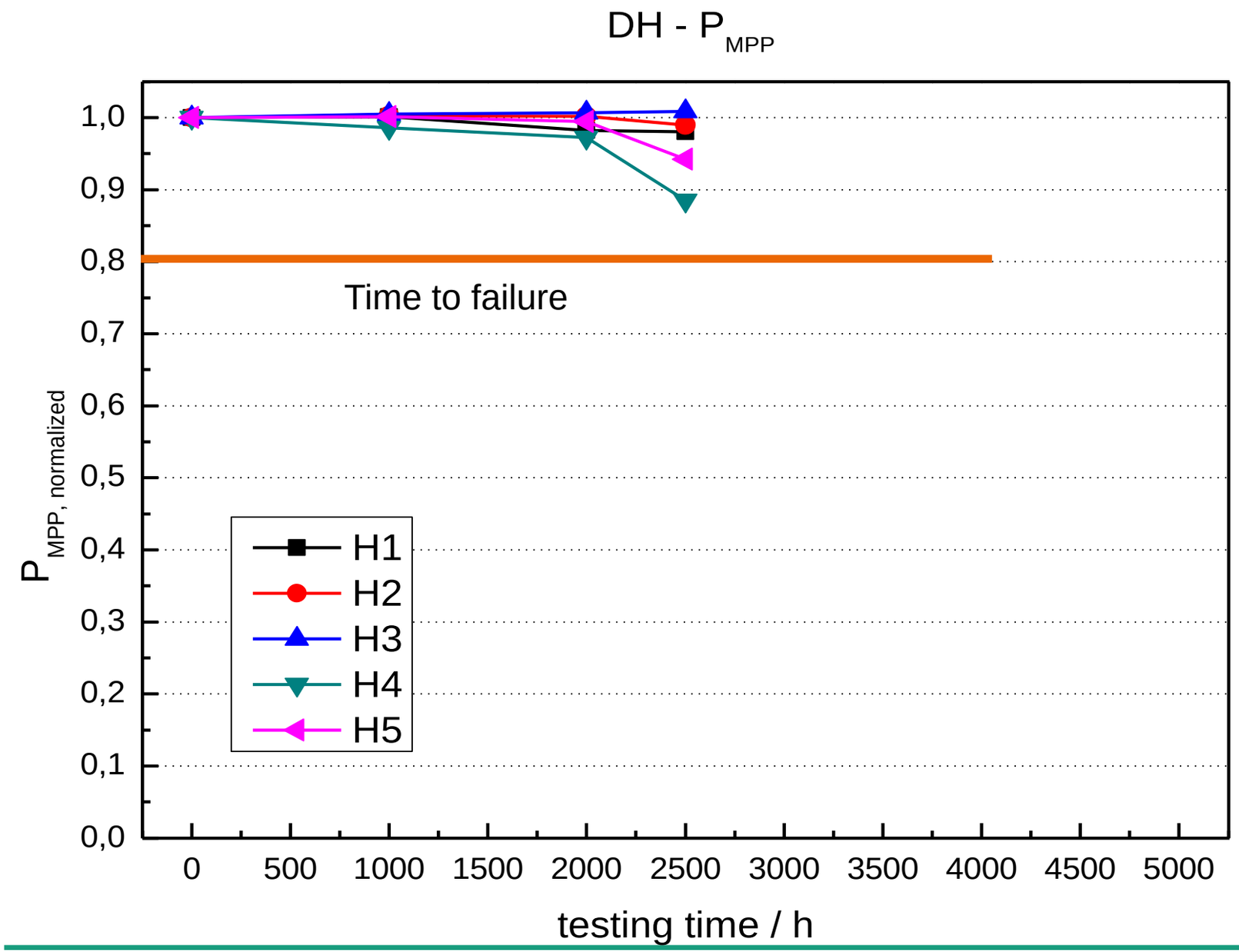

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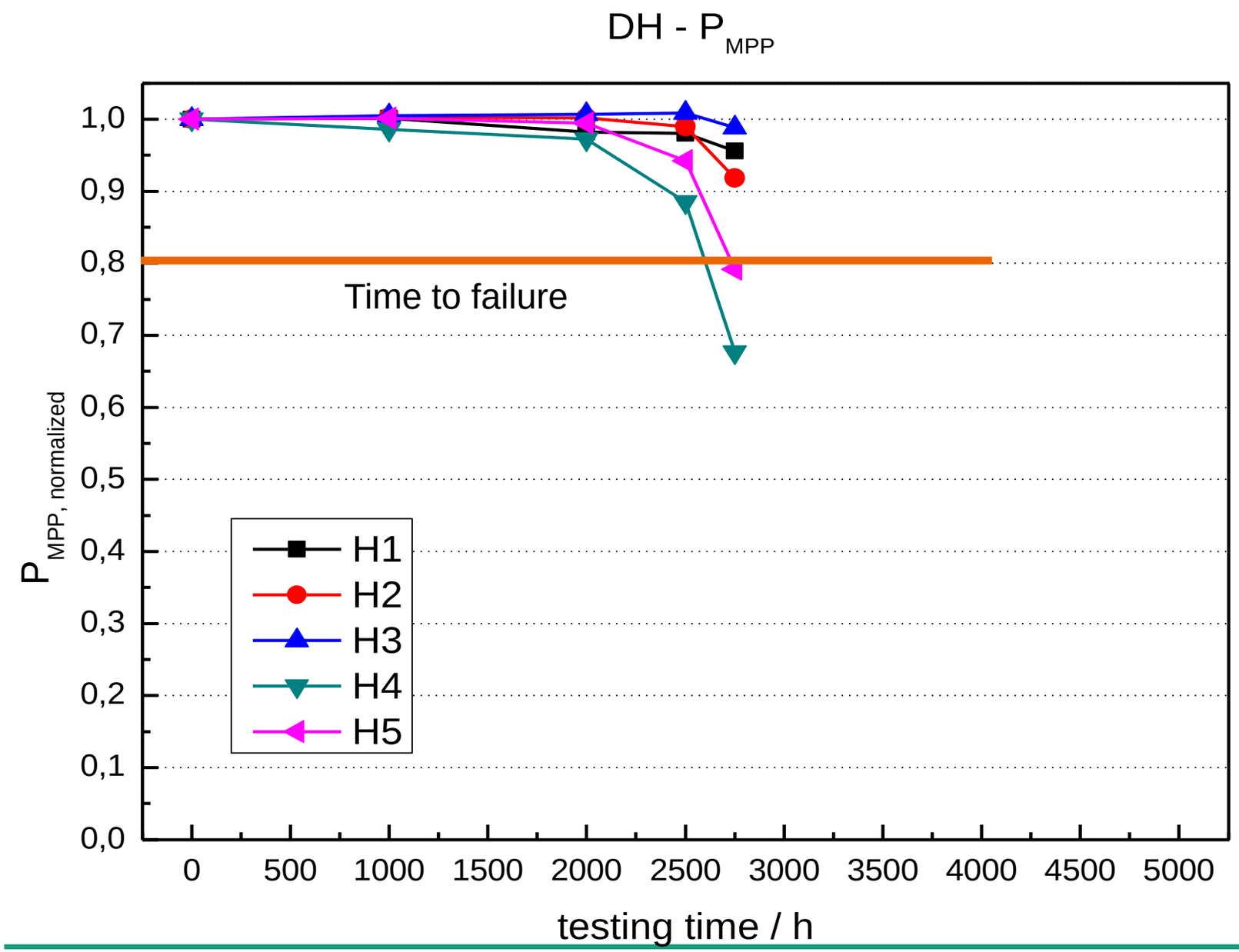

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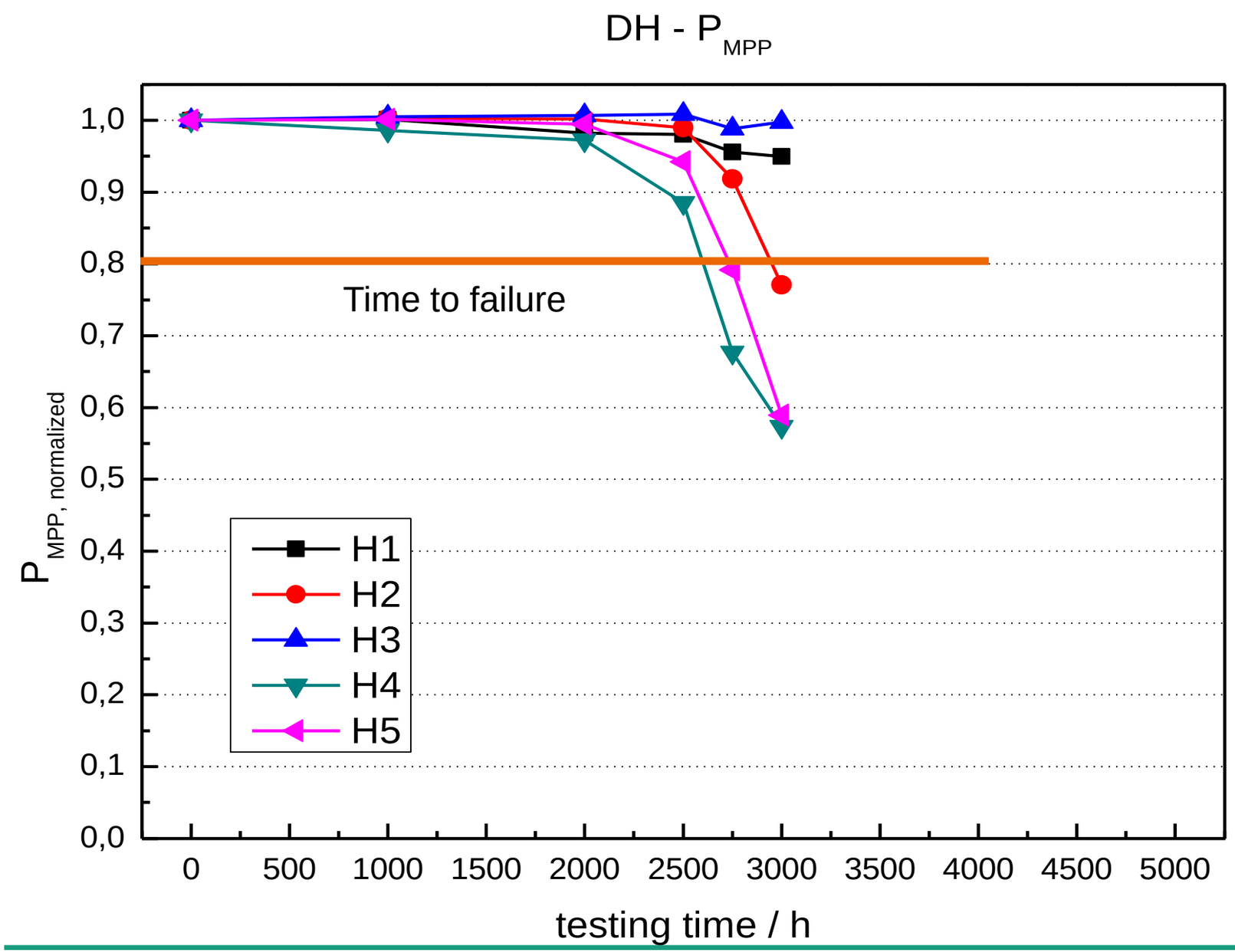

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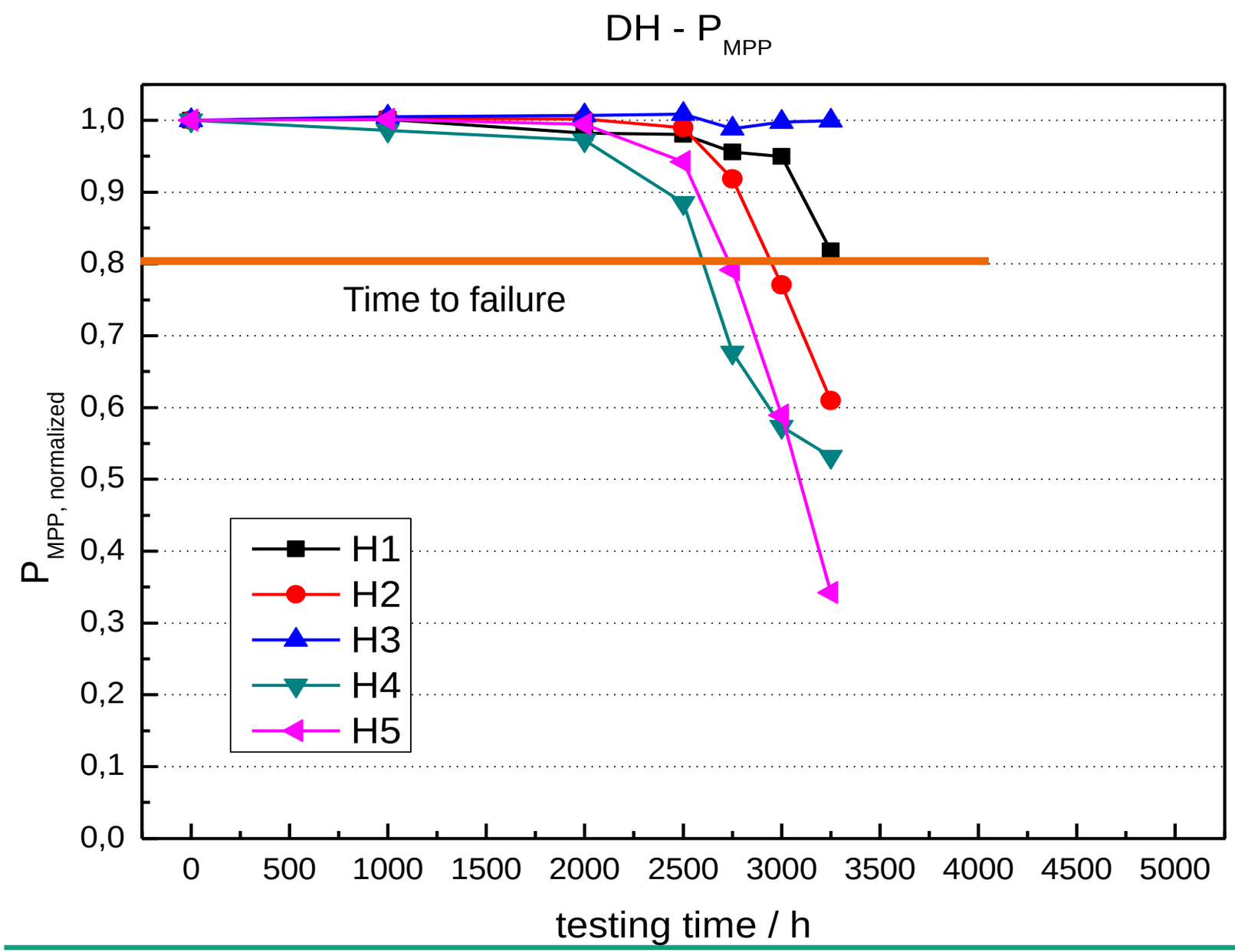

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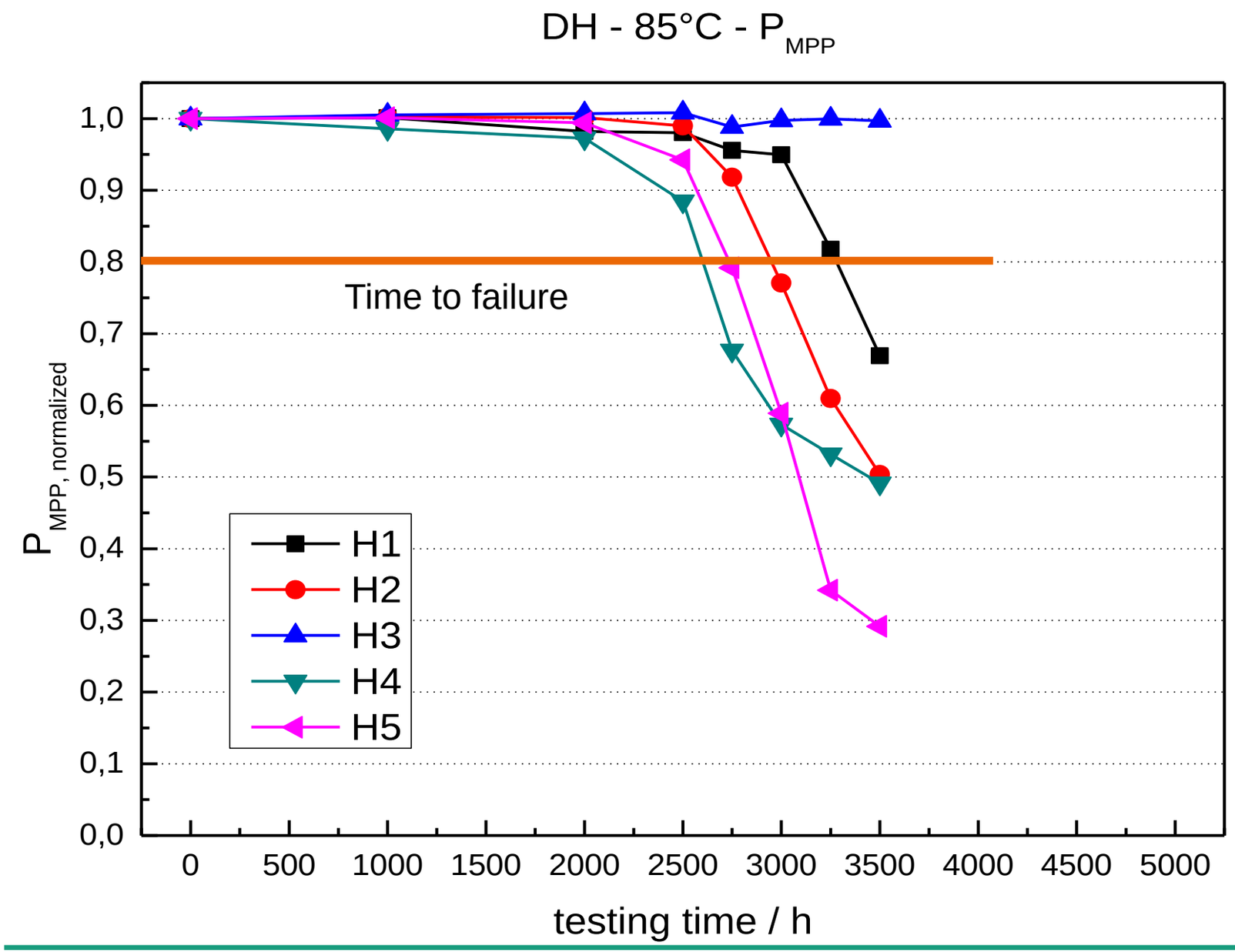

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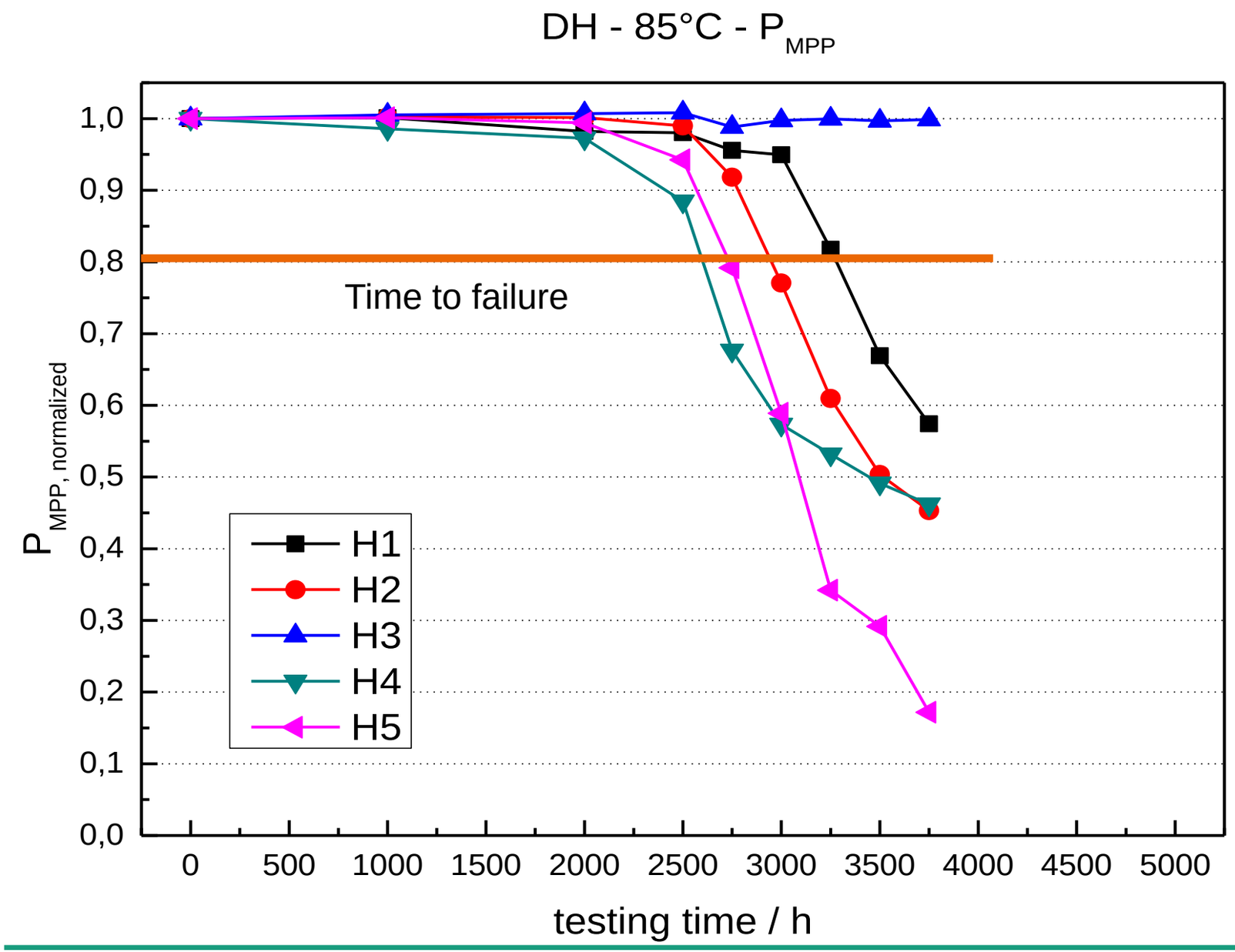

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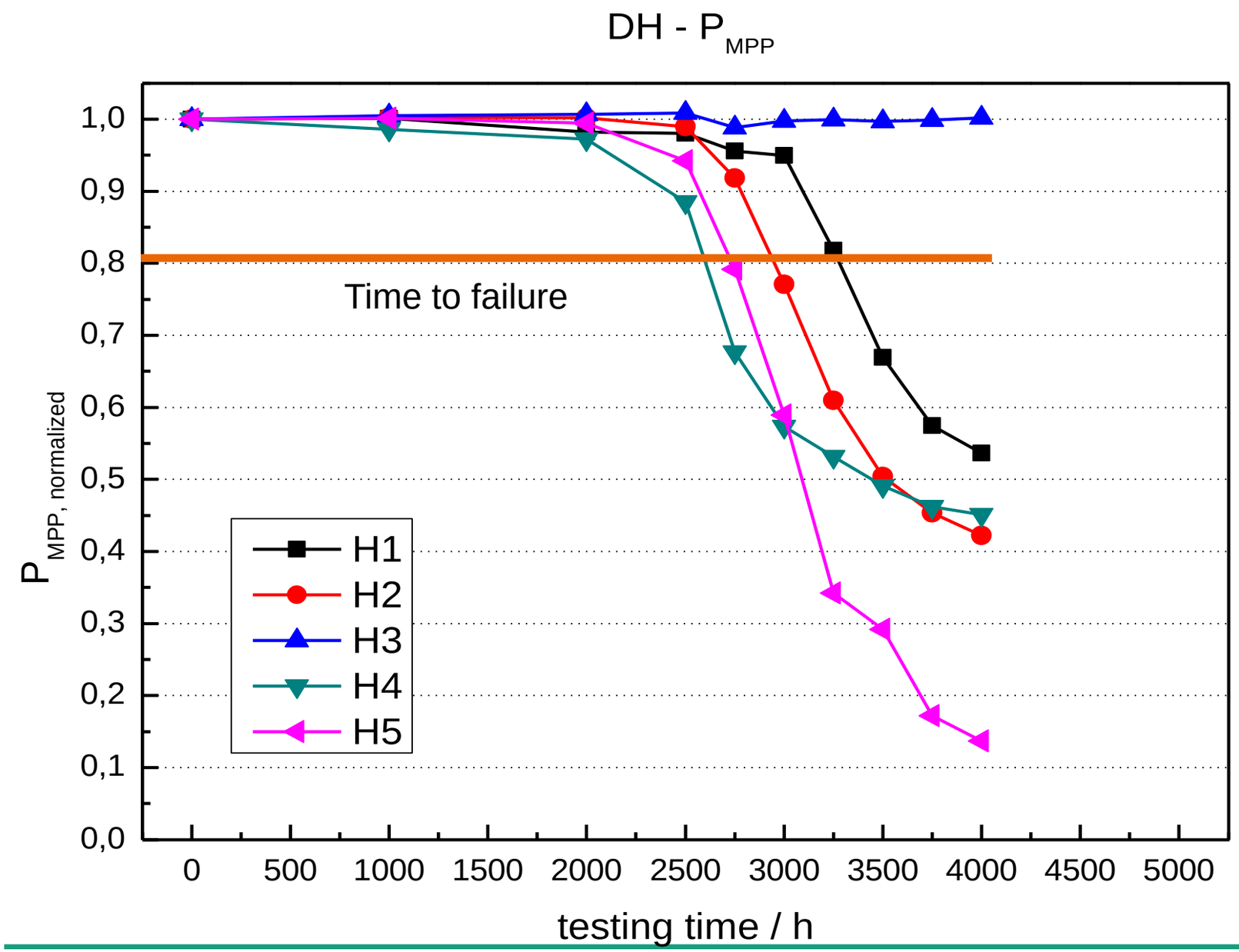

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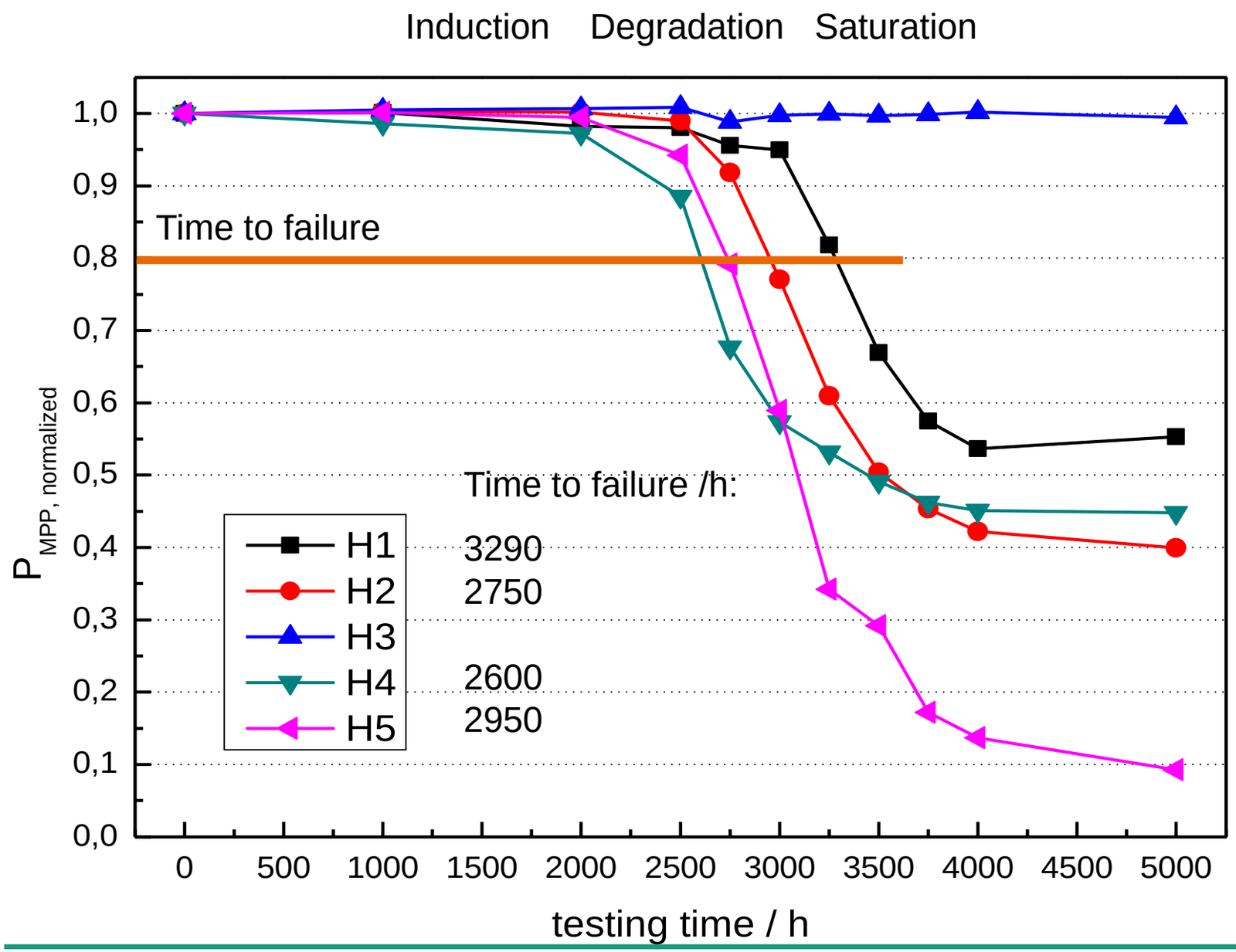

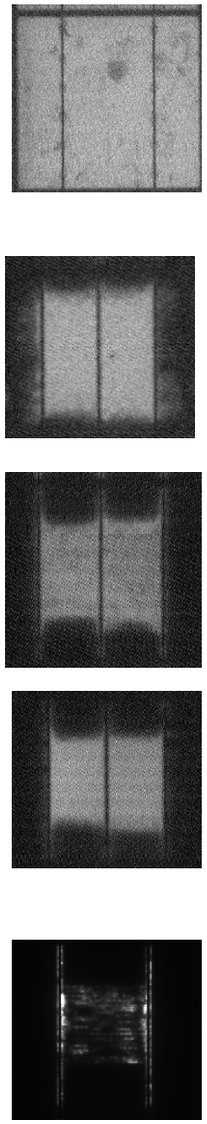

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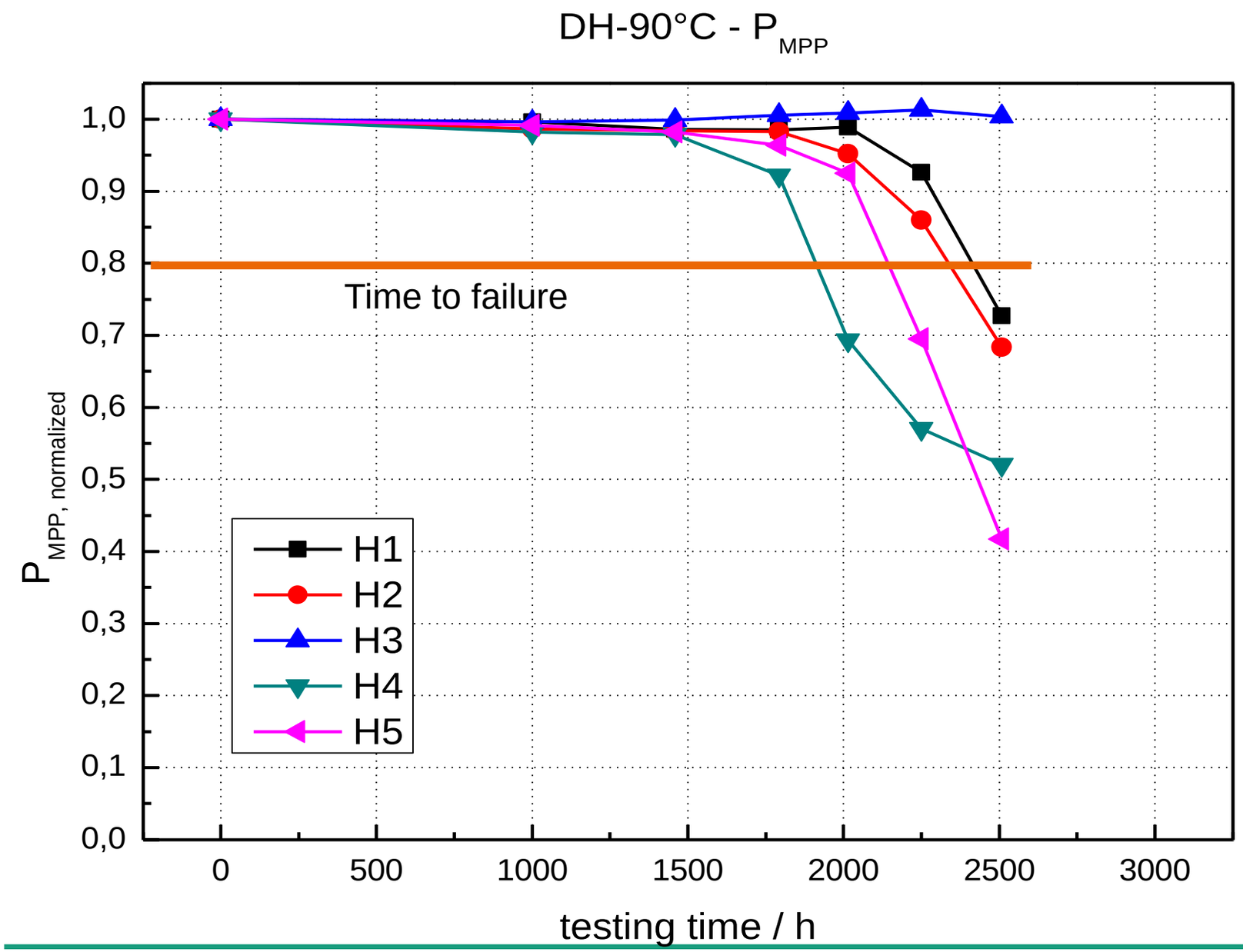

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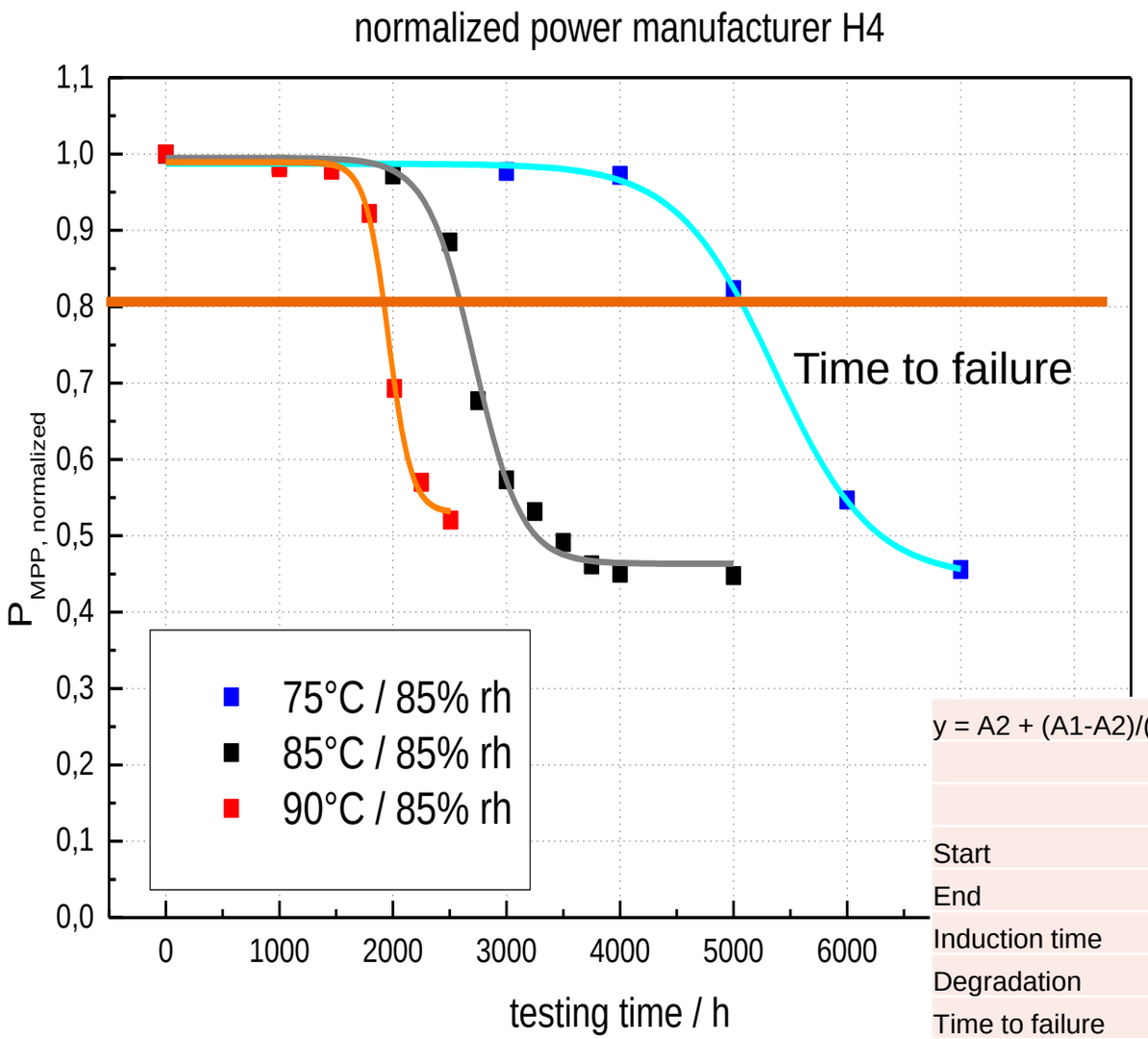
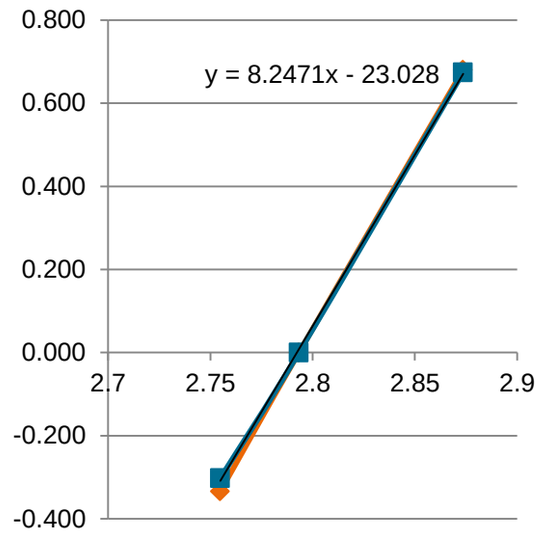
Evaluation of the parameters for time-transformation functions by ALT

Damp-heat testing at 85%rh@ 75°C, 85°C and @90°C





Arrhenius-Plot: Activation energy = 69 kJ/mol

y = A2 + (A1-A2)/(1 + exp((x-x0)/dx))		75°C		85°C		90°C	
		Value	Error	Value	Error	Value	Error
Start	A1	0,987	0,01	0,995	0,01	0,988	0,01
End	A2	0,445	0,01	0,463	0,01	0,556	0,01
Induction time	x0	5364	51,11	2717	30,84	1946	12,67
Degradation	dx	430	39,55	208	28,99	90	9,86
Time to failure	tlt	5117		2608		1928	
Acceleration a		0,51		1,00		1,35	

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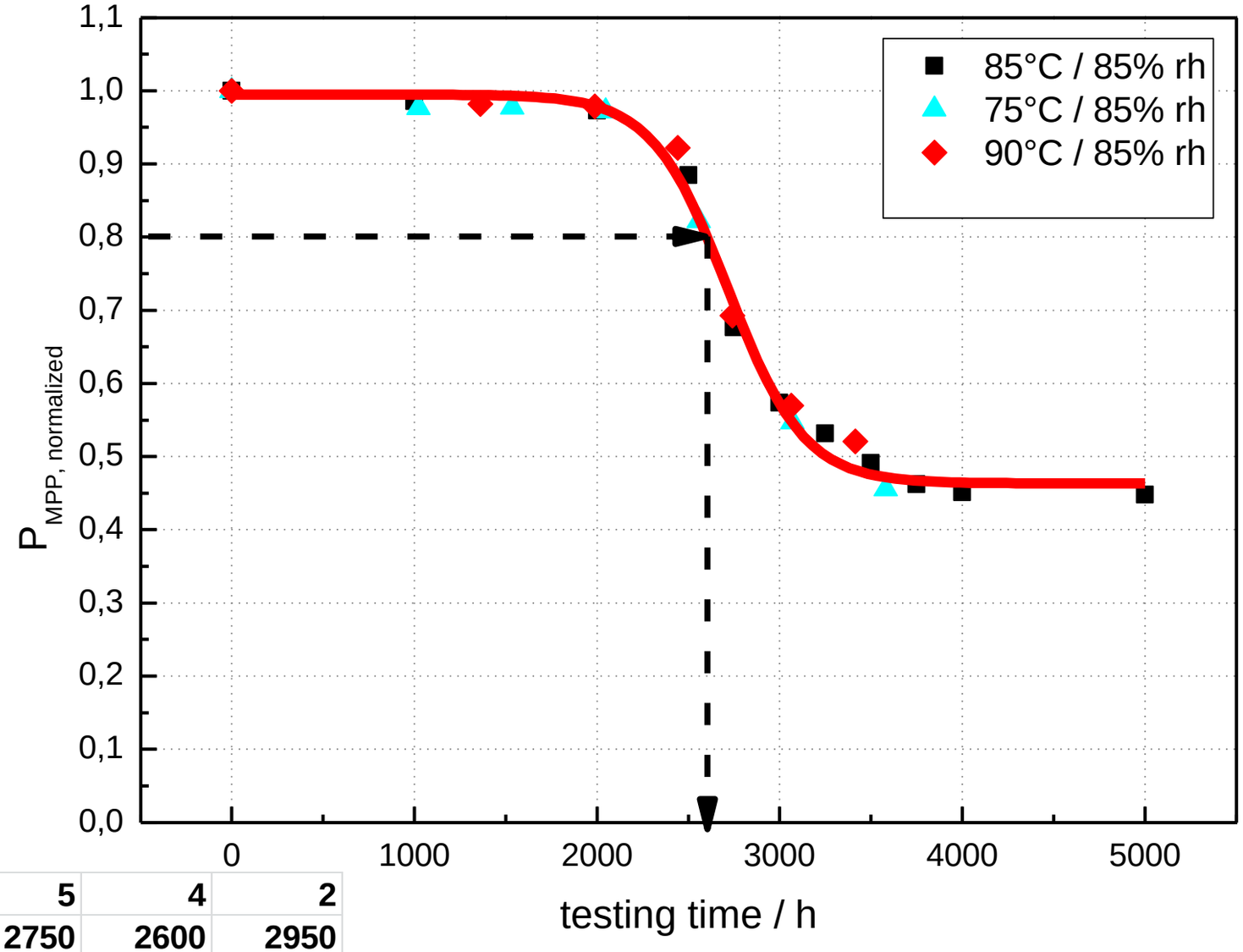
Evaluation of the parameters for time-transformation functions by ALT

$a = \exp\left[-(E_a / R)\cdot(1/T_1 - 1/T_2)\right]$



Module #	1	5	4	2
Lifetime @ 85°C/h	3290	2750	2600	2950
Induction time @ 85°C/h	3339	3105	2717	3033
Accelaration 75/85	1,85	1,85	1,95	1,7
Activation E / kJ/mol	64,5	63,7	69,2	55,0

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EU-FP7 project SOPHIA

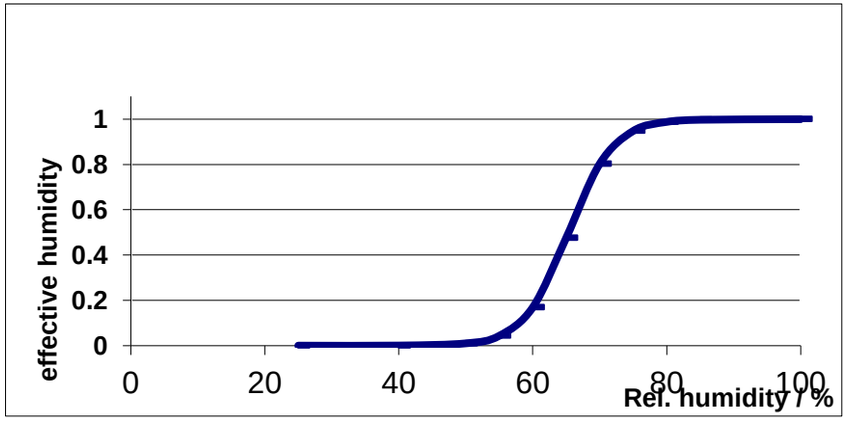
Work-sharing testing in different labs => poster by Jiang Zhu
Challenge: how to compare the results

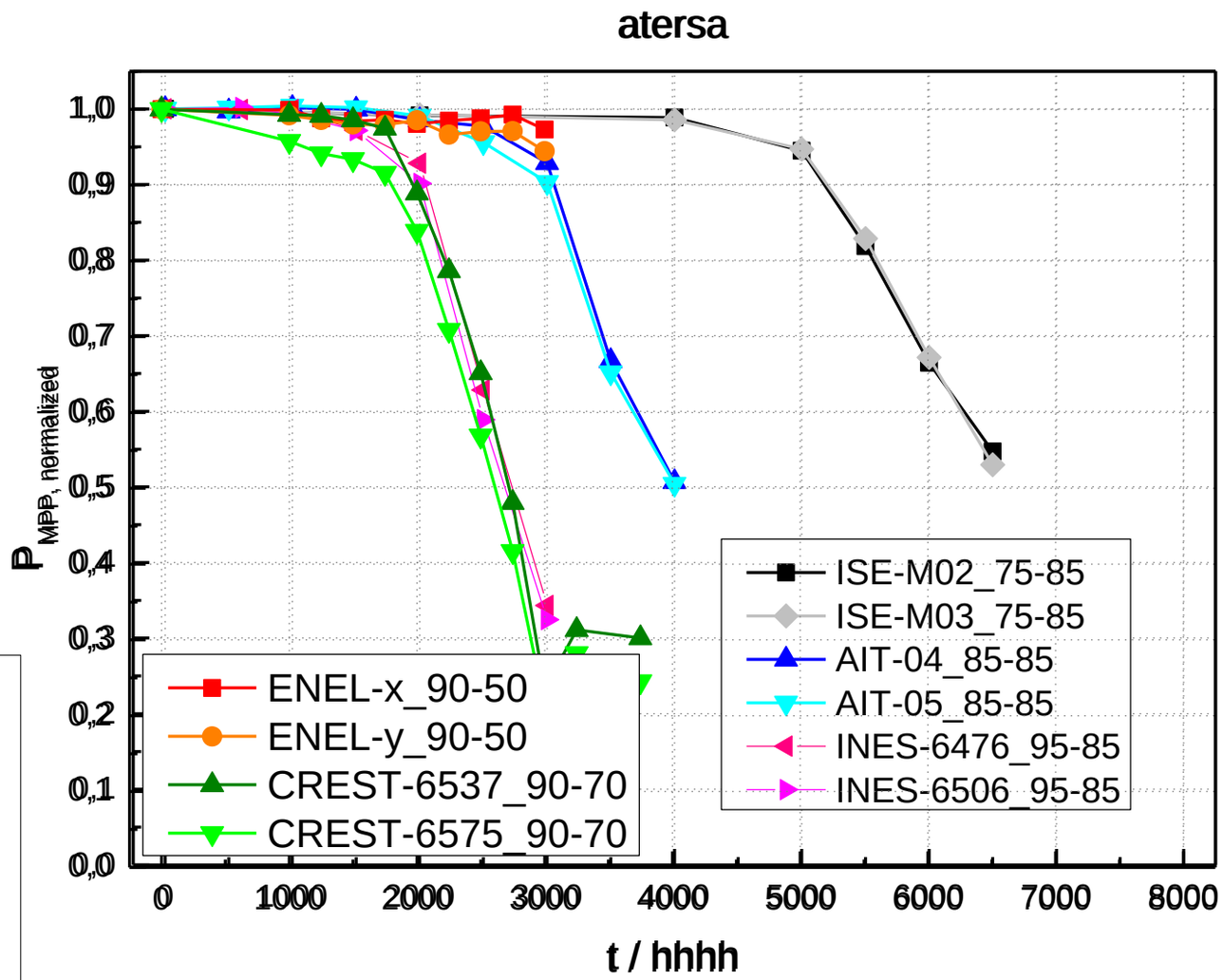
Average activation energy

50 kJ/mol

No serious degradation at 50%rh

Similar degradation at 70% and 85% rh: S-curve for eff. humidity





Koehl et al: Solar Energy Materials & Solar Cells 99 (2012) 282–291

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What are the weathering stresses? => Monitoring climatic conditions

Ambient climate and sample temperatures as 1min averaged time series

Corrosivity, salt concentration as yearly or monthly dose

City or reference:

Freiburg Germany

Arid

Sede Boqer

Israel

Alpine

Zugspitze

Germany

Tropical

Serpang

Indonesia

(operated by TÜV Rheinland)

Maritime

Pozo Izquierdo

Gran Canaria

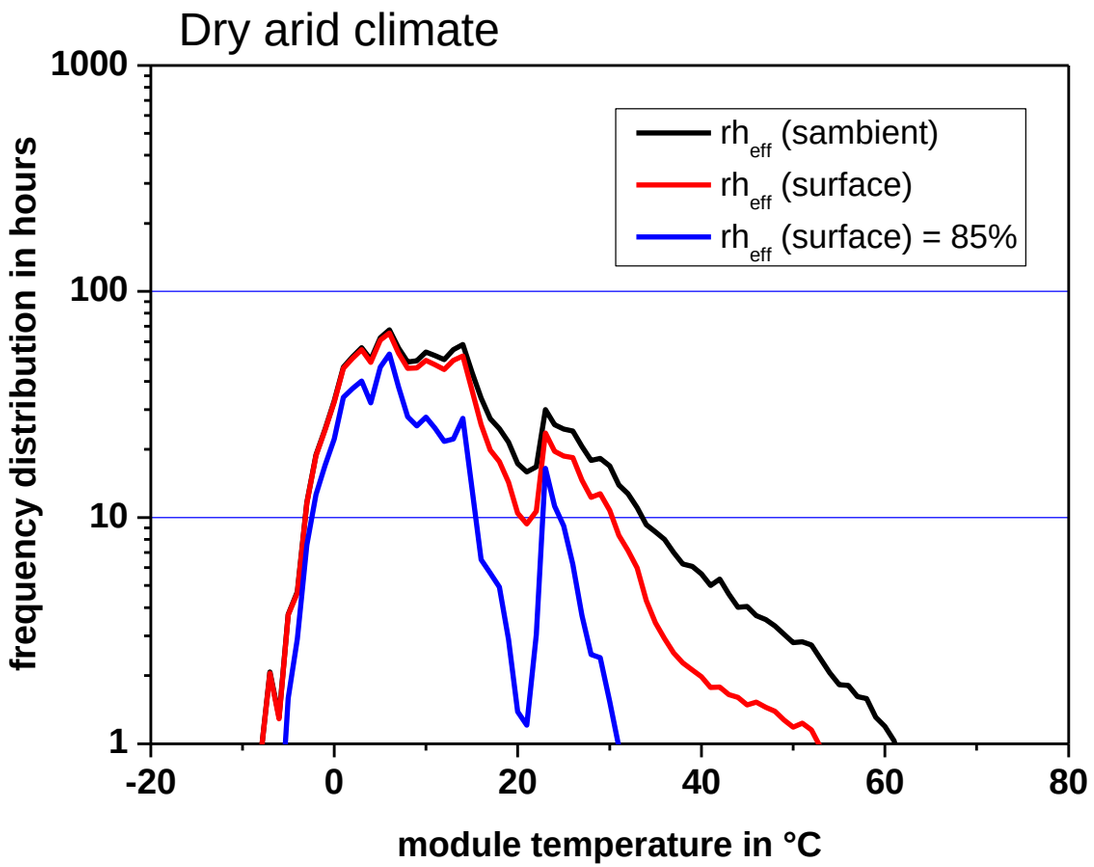
Modeling micro-climatic moisture stress factors for back-sheets and cell edges

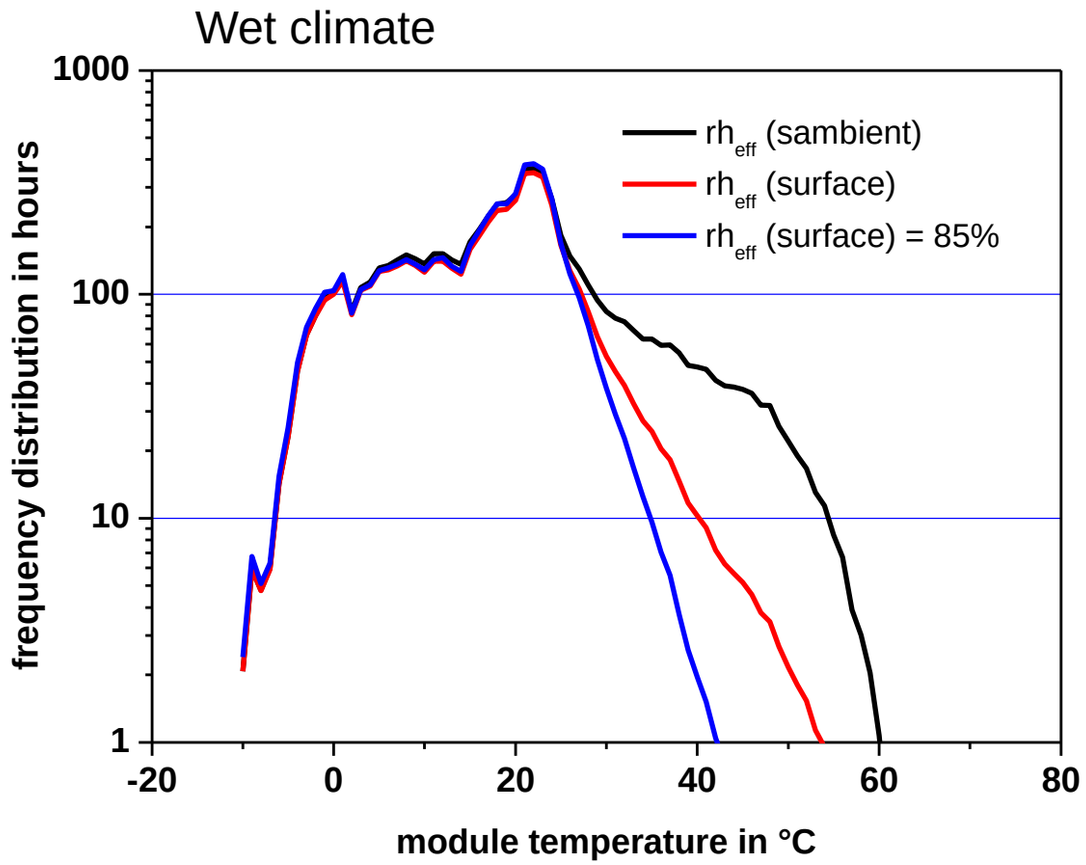
1.) $T_{mod} = T_{amb} + H/(u_0 + u_1 v)$ modeling the module temperature

2.) $rh(T_{mod}) = rh(T_{amb}) * P_{sat}(T_{mod}) / P_{sat}(T_{amb})$ takes into account the higher module temperature

3.) $rh_{eff} = 1/(1 + \exp(-s*rh) \cdot (1/0{,}01 - 1))$ effective humidity gives more weight to periods with high rh

4.) $\Delta t_{85} = \Delta t * rh_{eff} / 0{,}85$ relates to the moisture level during testing





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Time-transformation functions for major degradation processes

5.) Process kinetics depend on module temperature (Time Transformation Function):

$$t_{test} = \text{Lifetime (years)} \cdot \Sigma_i \{\Delta t_i(rh_{eff}, T_{mod,i}) \cdot \exp[-(E_a / R)\cdot(1/T_{test} - 1/T_{mod,i})]\}$$

E_a = activation energy for the rate dominating degradation process

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Evaluation of the service life time in different climates

Activation energy is more important than time to failure

E_a = 70 kJ/mol

For tropical climates

ALT time @ 85°C= 1500h

Time to failure = 2600h is longer

>> passed

E_a = 55 kJ/mol

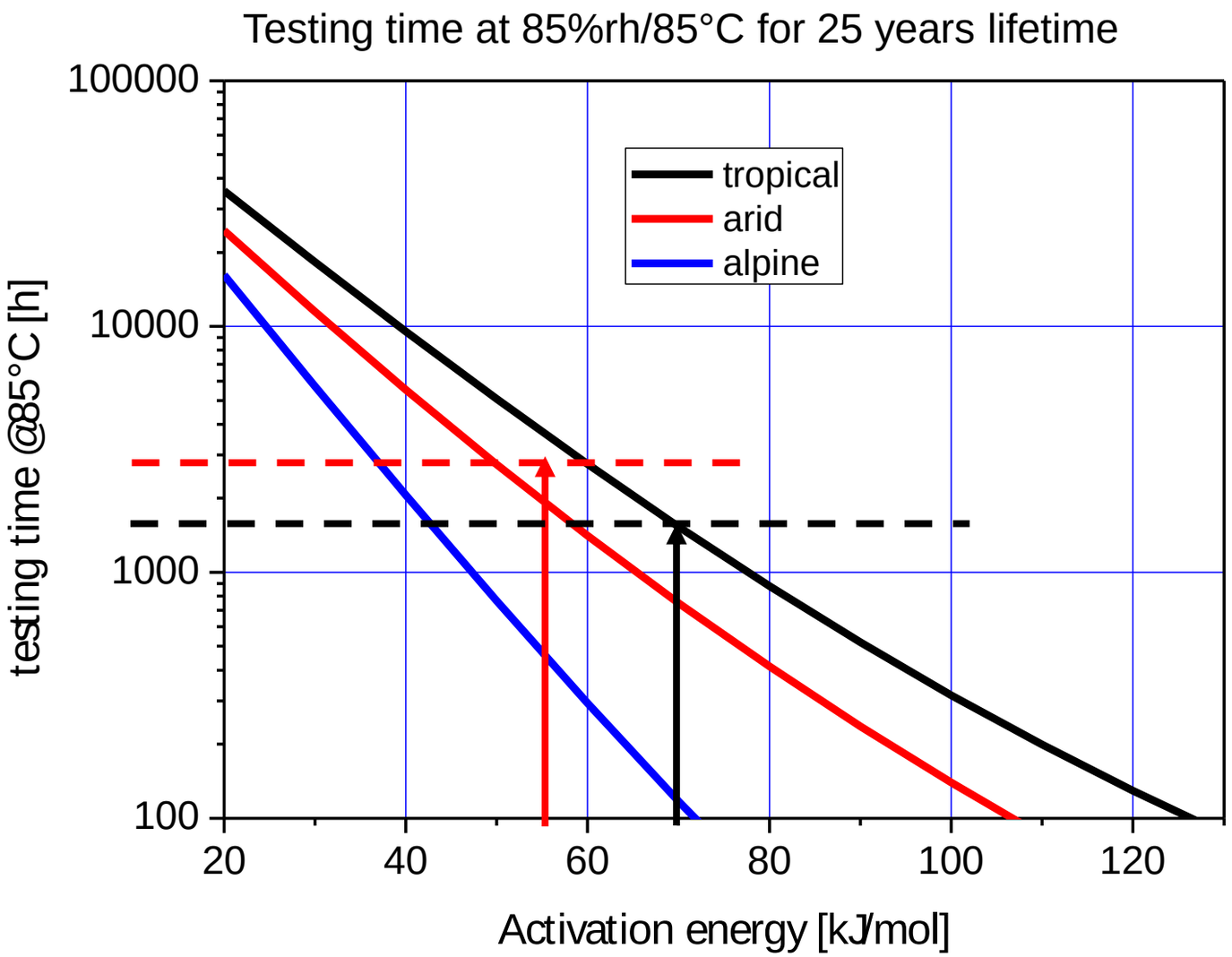
For tropical climates

ALT time @ 85°C: 3700h

Time to failure = 2950h is shorter

>> failed

But good enough for deserts



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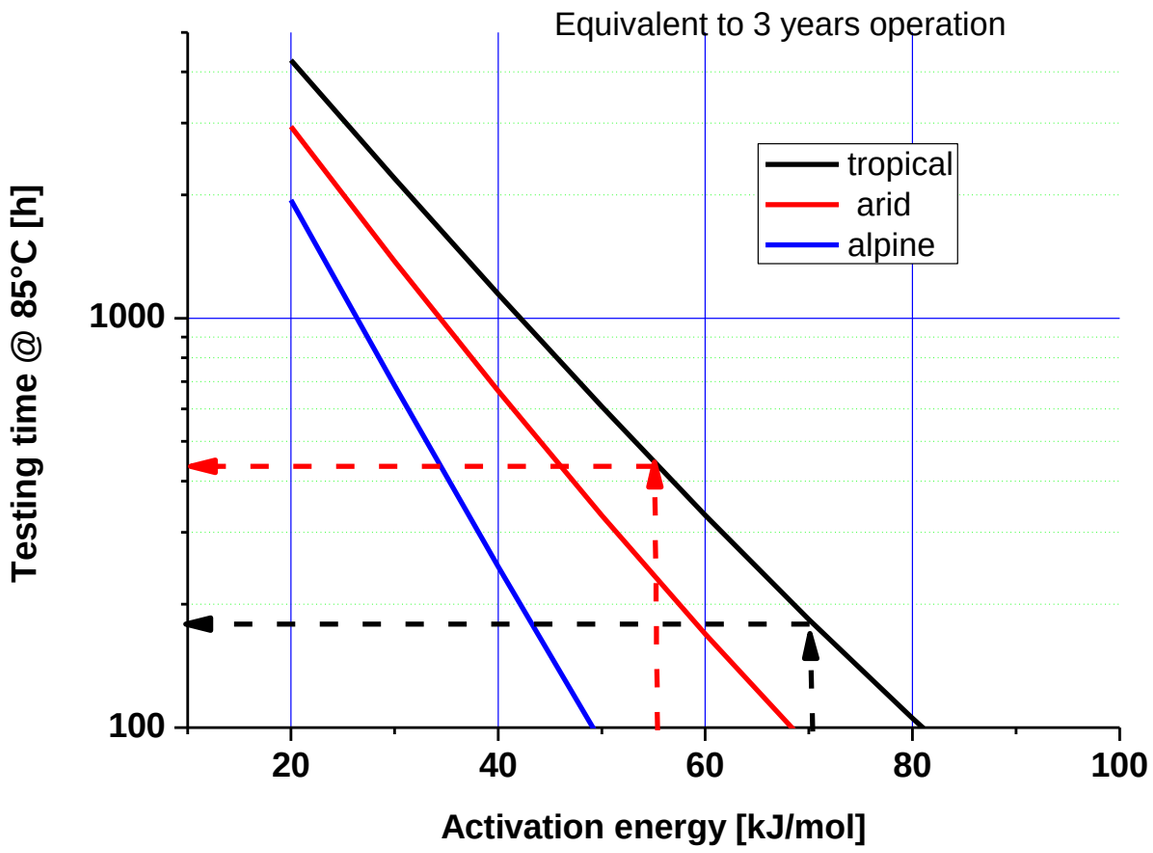
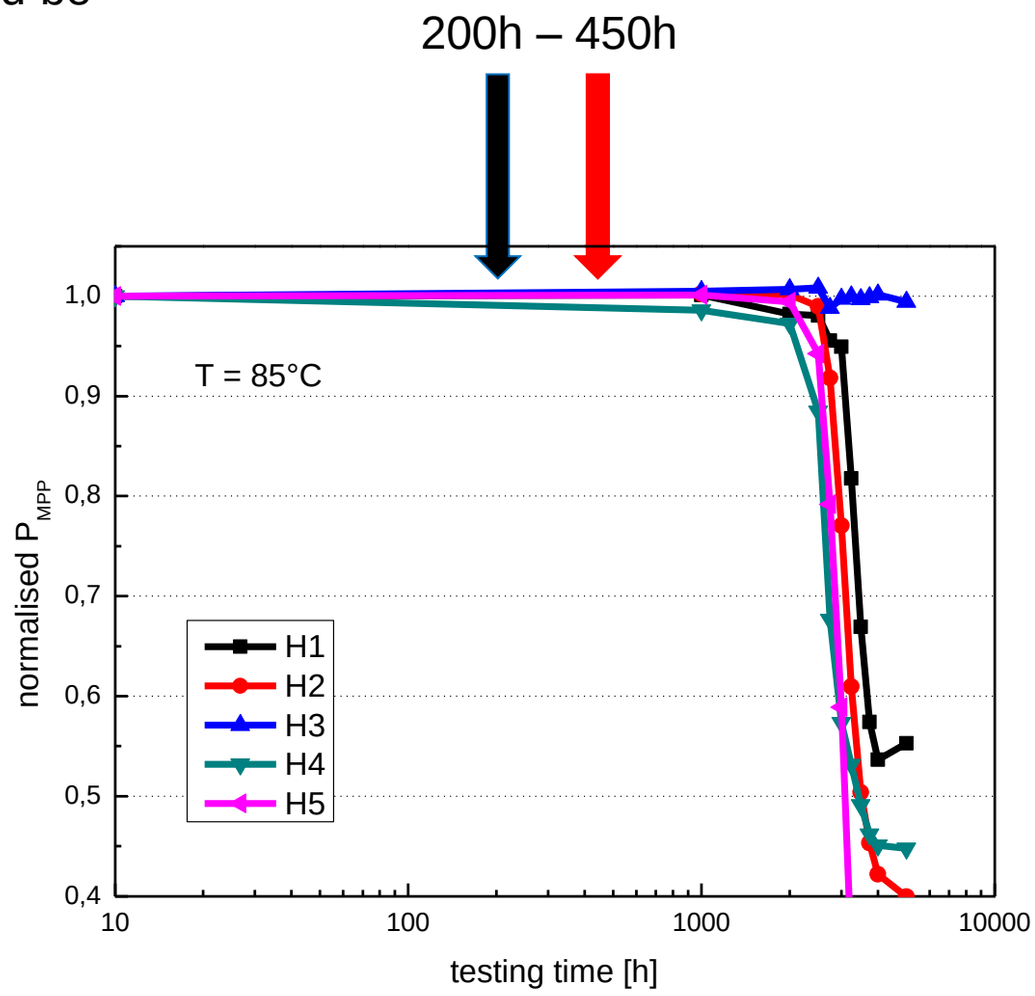
Modeling expected degradation for validation by outdoor exposure

Power reduction after 3 years outdoor exposure < 3%

Corresponding 85rh@85°C test for the tropical site would be 200h for 70kJ/mol and 450h for 55 kJ/mol





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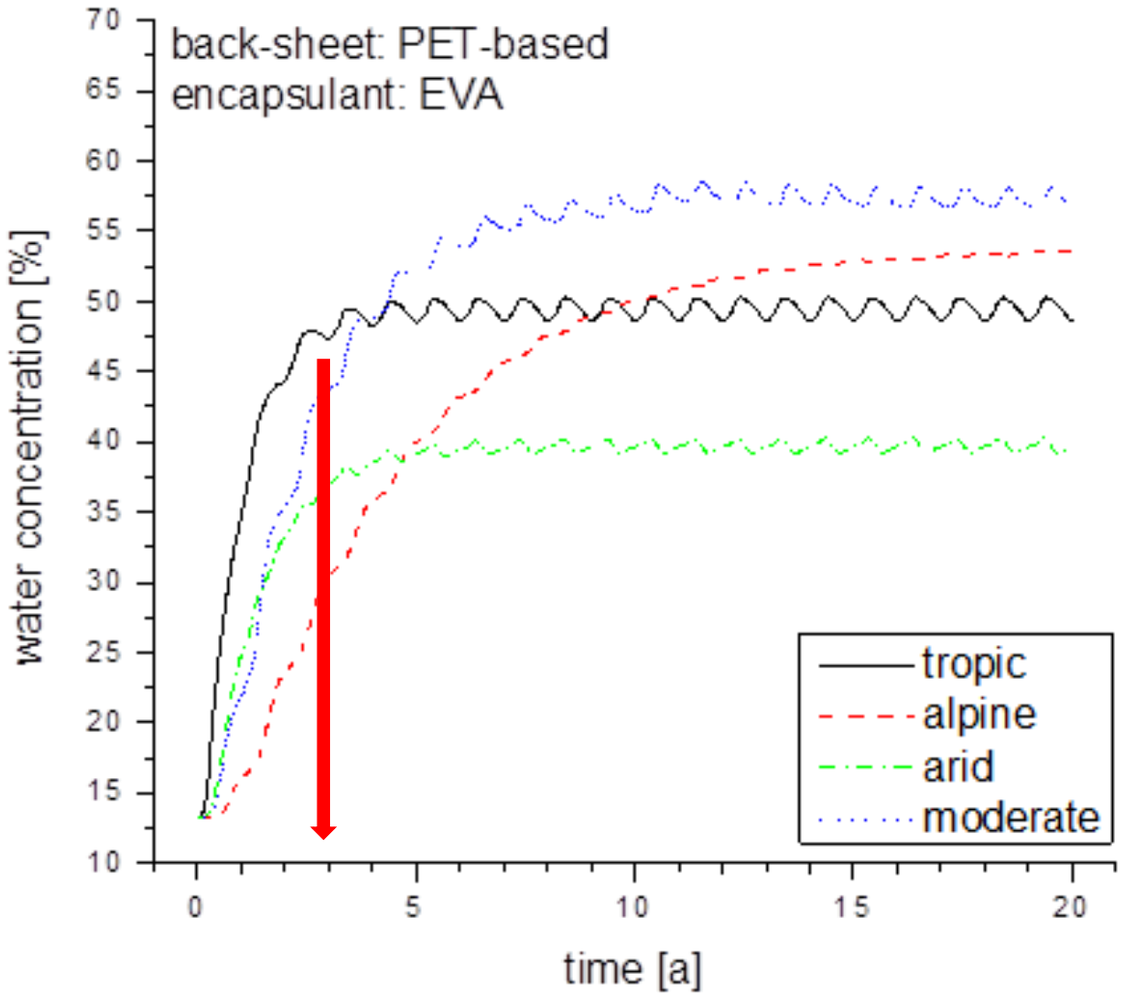
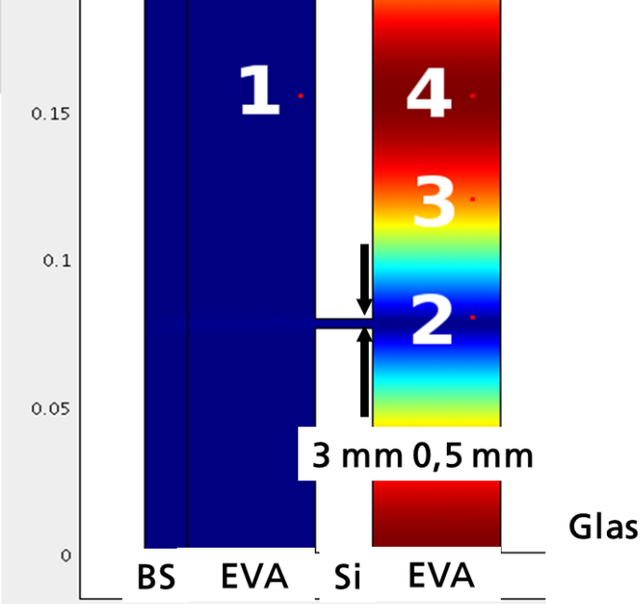
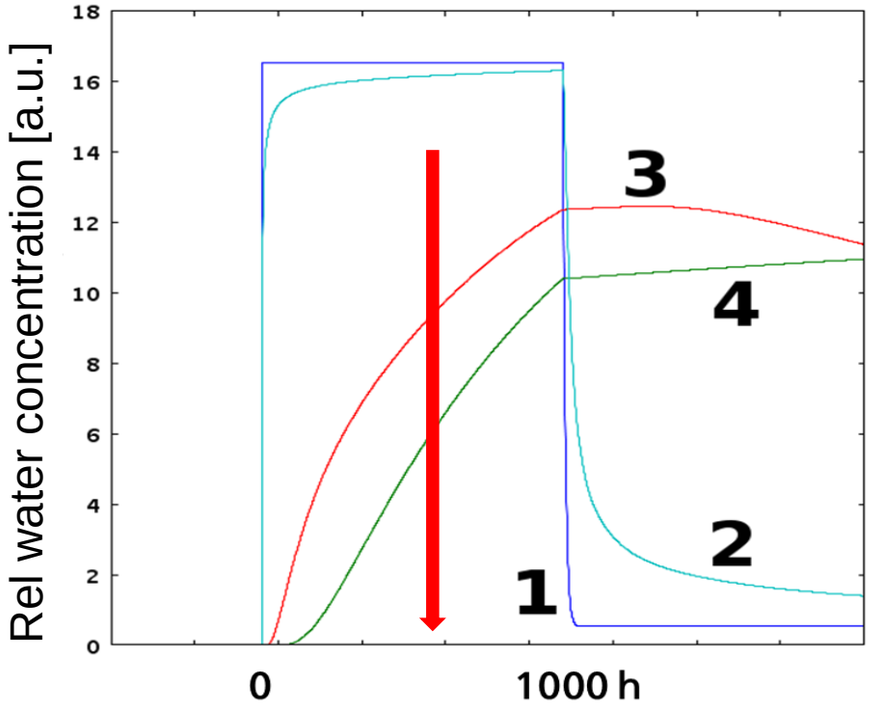
Modeling micro-climatic stress factors front-side

Simulation of module humidity by FEM based on measured temperature dependent permeation/diffusion coefficients







Damp-heat testing 85%rh @ 85°C

J. Wirth, Diploma Thesis, University of Freiburg, 2008.

J. P. Hülsmann et al., "Simulation of Water Vapor Ingress into PV-Modules under Different Climatic Conditions," Journal of Materials, vol. 2013, doi:10.1155/2013/102691

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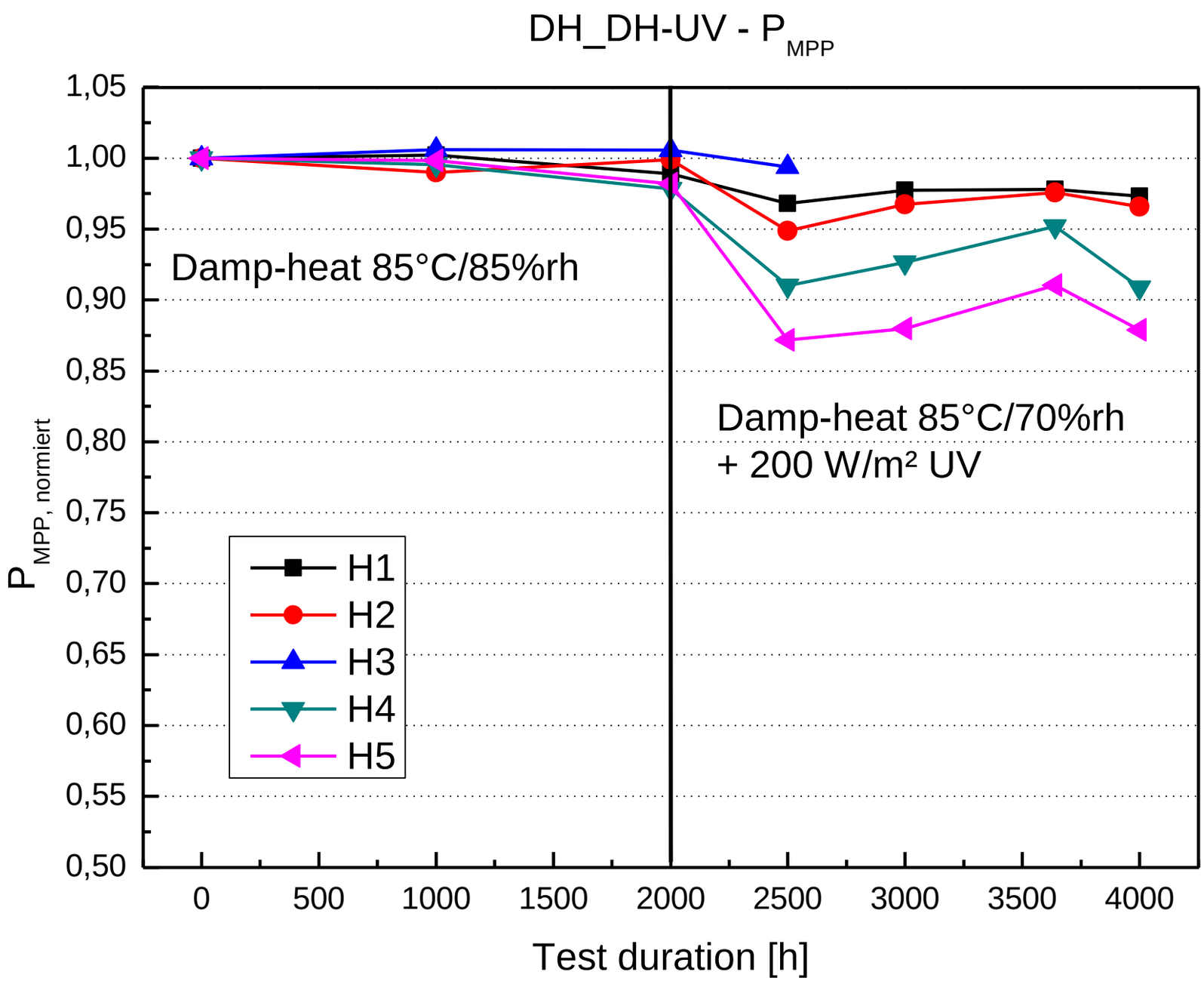

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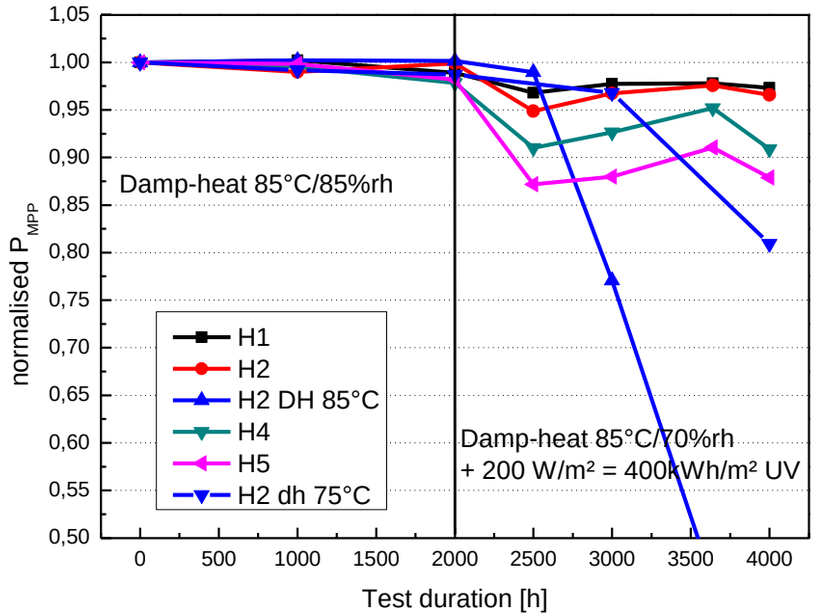
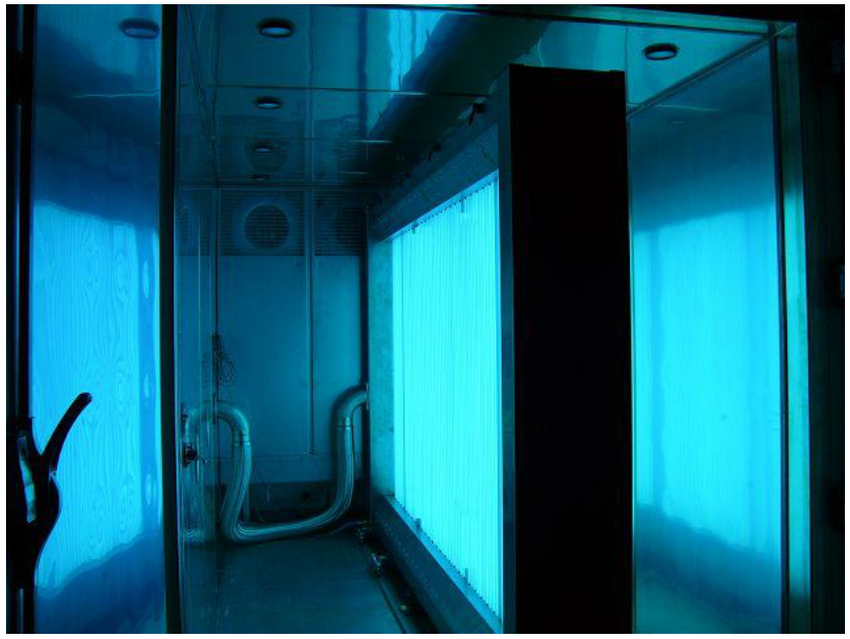
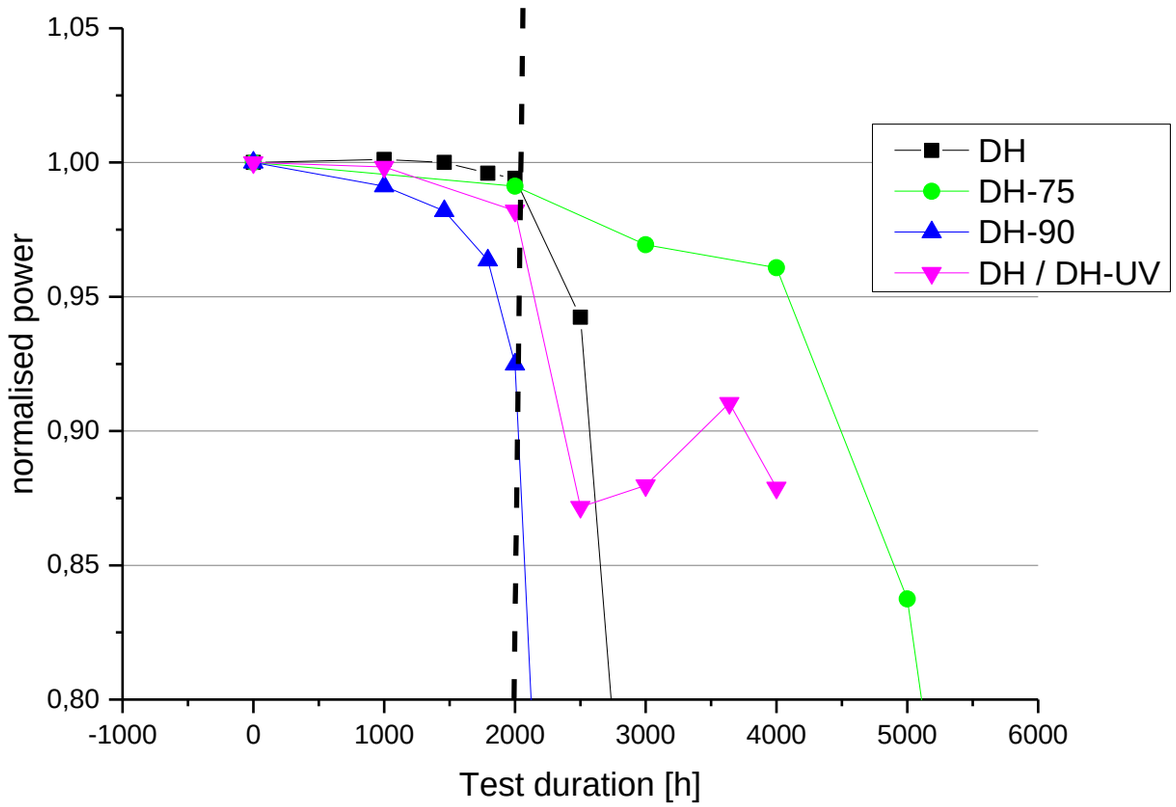


Is high humidity relevant?

Is irradiation healing?

Is constant load testing relevant?





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Thank you for your attention
Workshop to be continued:

SOPHIA Workshop PV-Module Reliability

June 3rd– June 4th, 2014, Freiburg (Germany)

From Type Approval to Accelerated Life Testing (ALT)

organized by Fraunhofer ISE (Michael Köhl) and JRC (Tony Sample)

www.pv-reliability.com

European Commission

Fraunhofer ISE