Linking accelerated ageing tests and outdoor testing

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How to validate Accelerated Life Testing ?

- How can failure modes of innovative modules be detected within a few years operation?
- Are Accelerated Service Life tests a mirror of the reality?

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

Alpine
Zugspitze
Germany

Arid
Sede Boqer
Israel

Tropical
Serpang
Indonesia
(operated by
TÜV Rheinland)

Maritime
Pozo Izquierdo
Gran Canaria

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

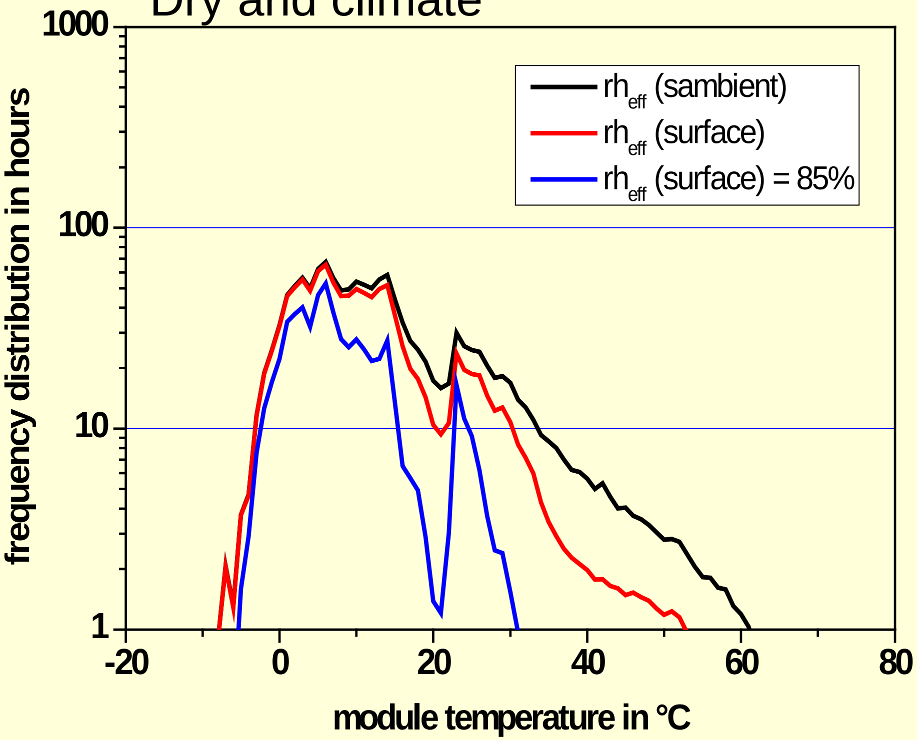
1.) $T_{mod} = T_{amb} + H/(u_0 + u_1 v)$ modeling the module temperature

2.) $rh(T_{mod}) = rh(T_{amb}) * P_{sat}(T_{mod}) / P_{sat}(T_{amb})$ accounts for higher module temperature

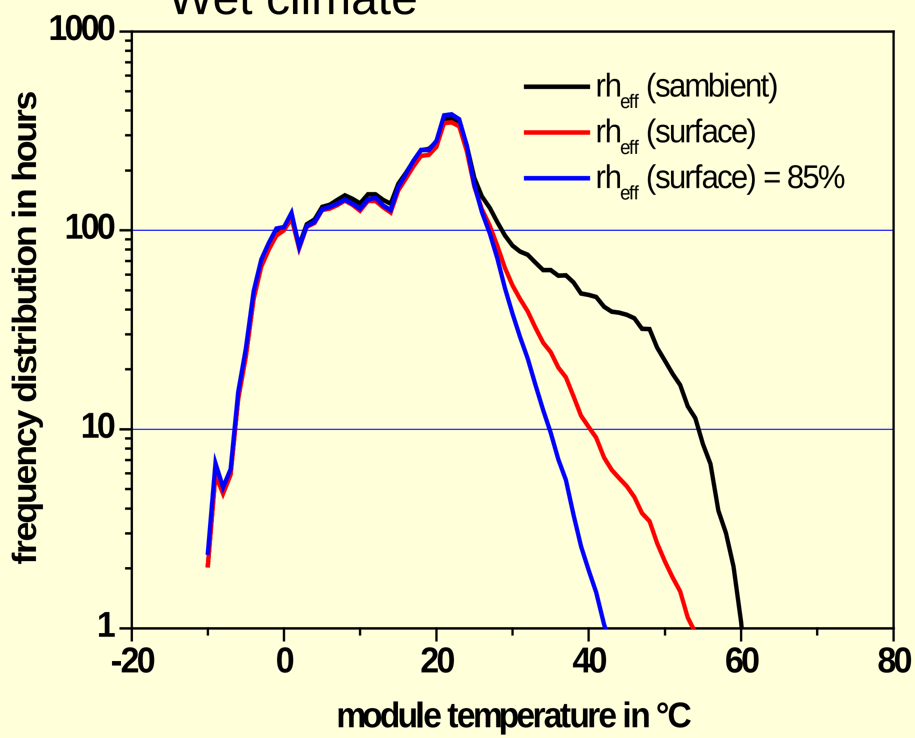
3.) $rh_{eff} = 1/(1 + \exp(-9{,}4 rh) \cdot (1/0{,}01 - 1))$ effective humidity gives more weight to periods with high rh

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

Dry arid climate



Wet climate



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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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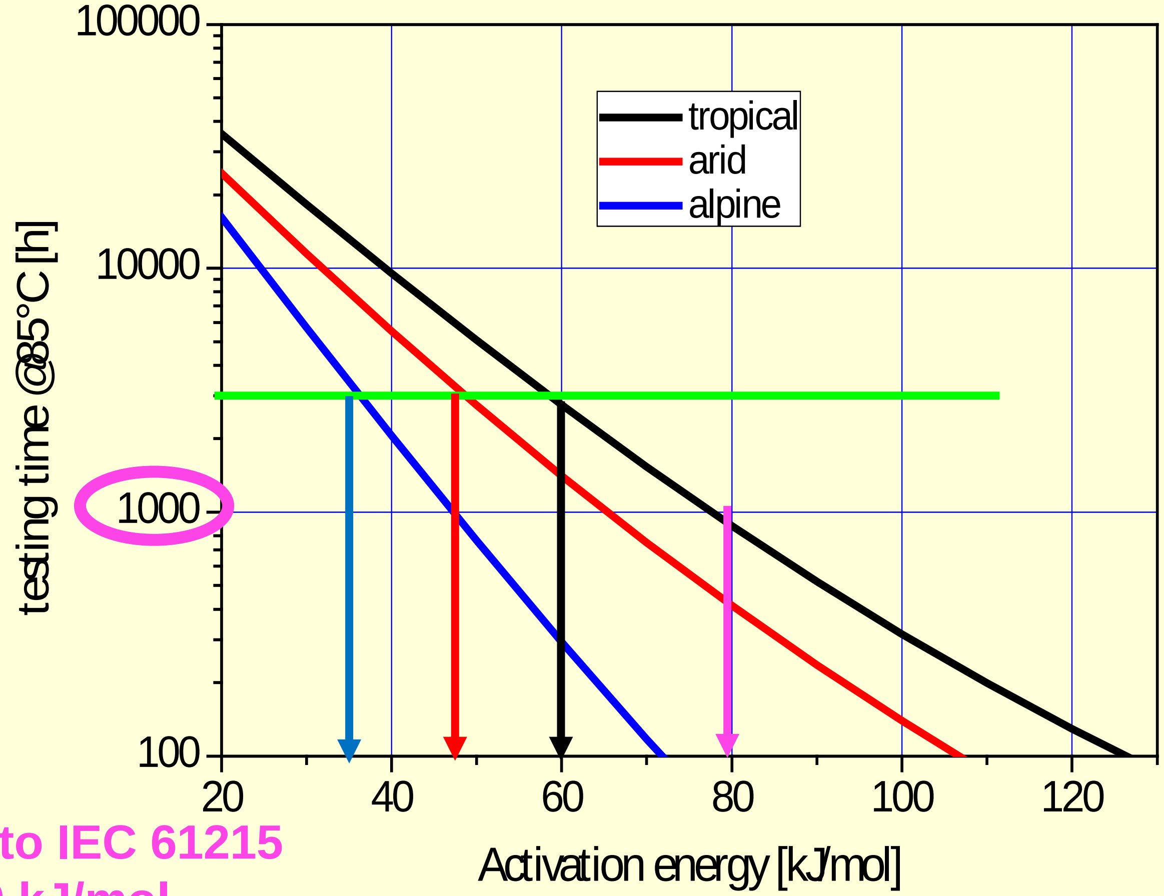
Modeling corresponding ALT – conditions for micro-climatic moisture stress

Testing time at 85%rh/85°C for 25 years lifetime

Example:
Time to failure @ 85°C/85%rh:

3000h



E_a > 35 kJ/mol for alpine climates

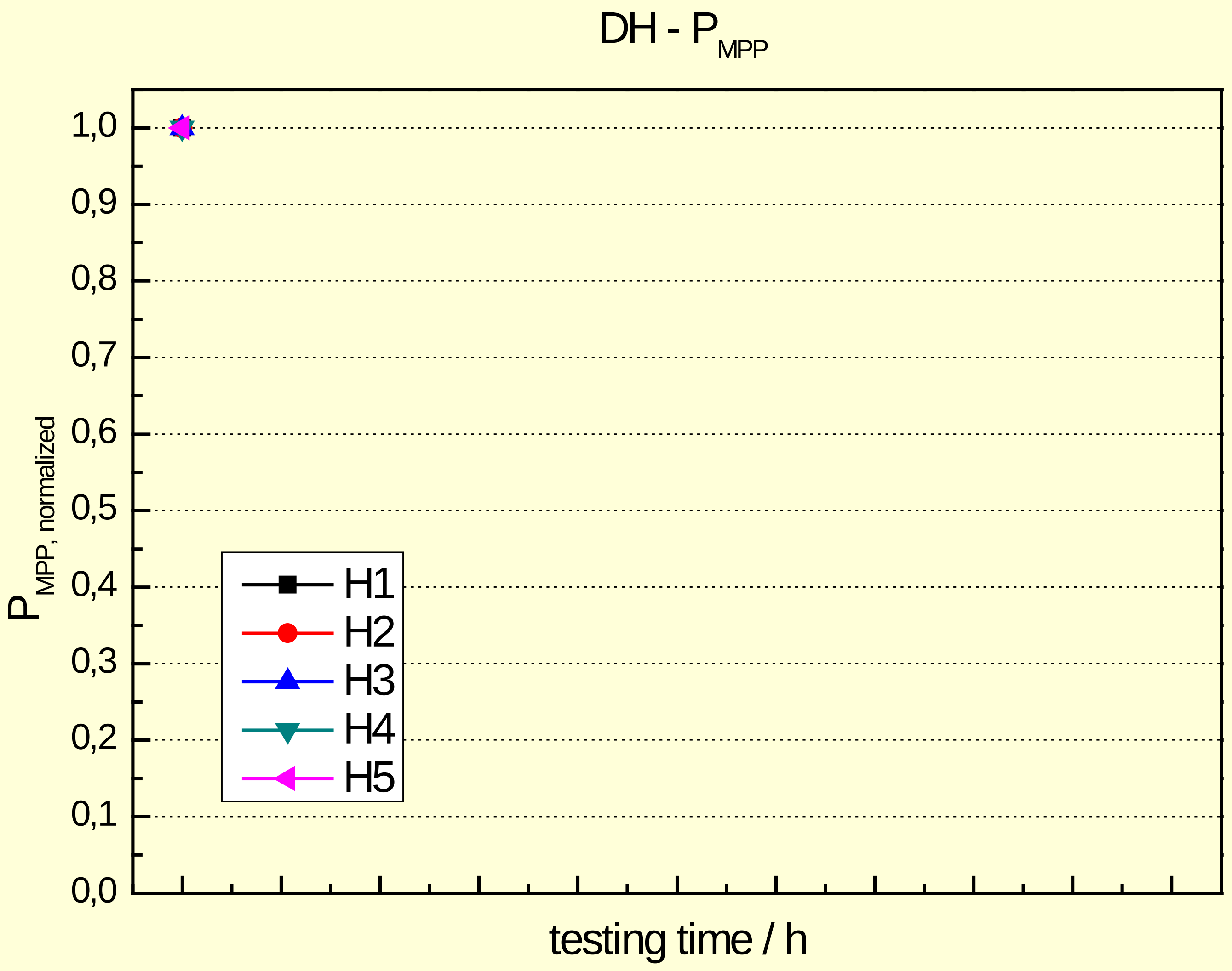
E_a > 50 kJ/mol for arid climates

E_a > 60 kJ/mol for tropical climates

Type approval test according to IEC 61215 would be sufficient for E_a > 80 kJ/mol

Evaluation of the parameters for time-transformation functions by ALT

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



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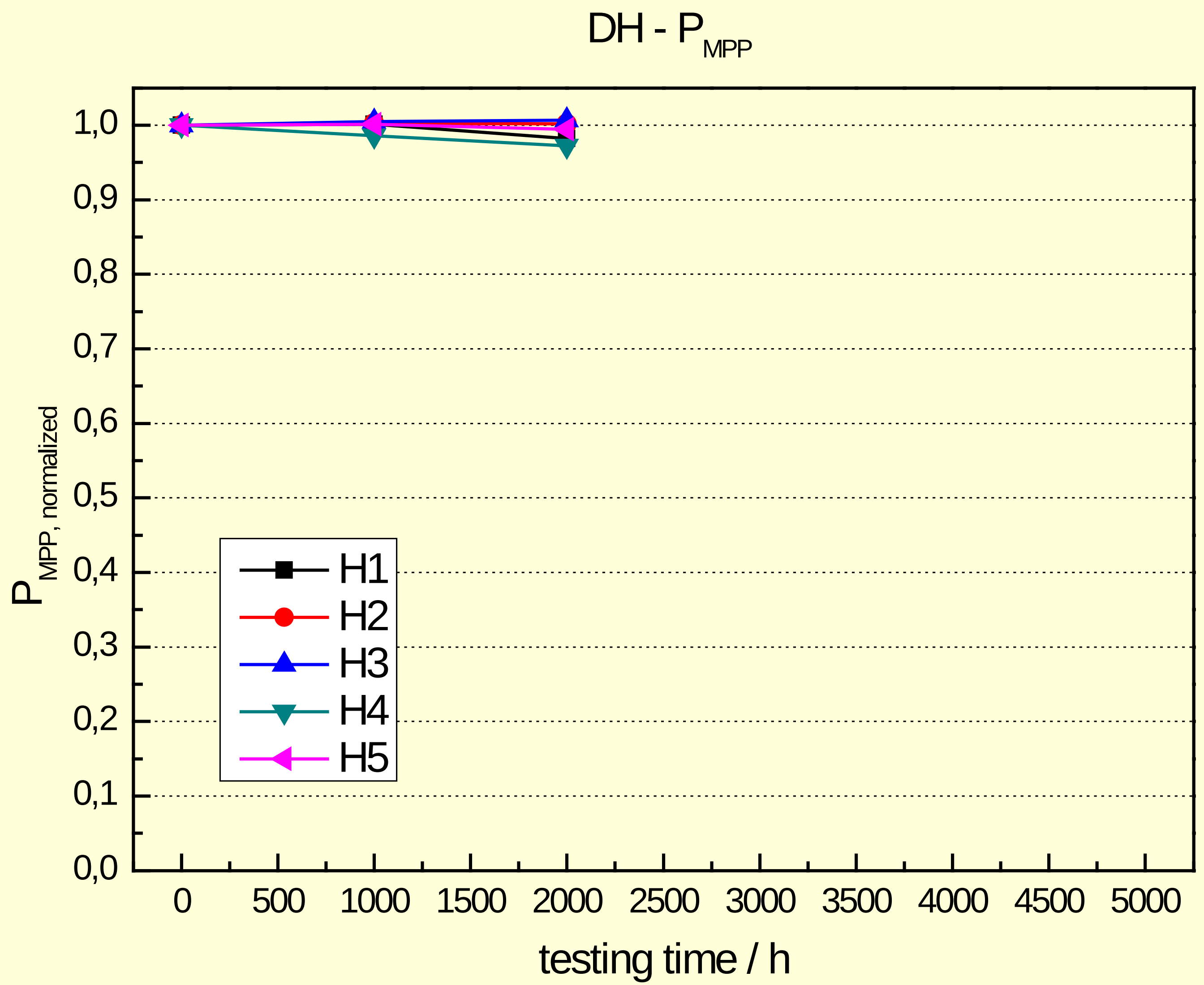
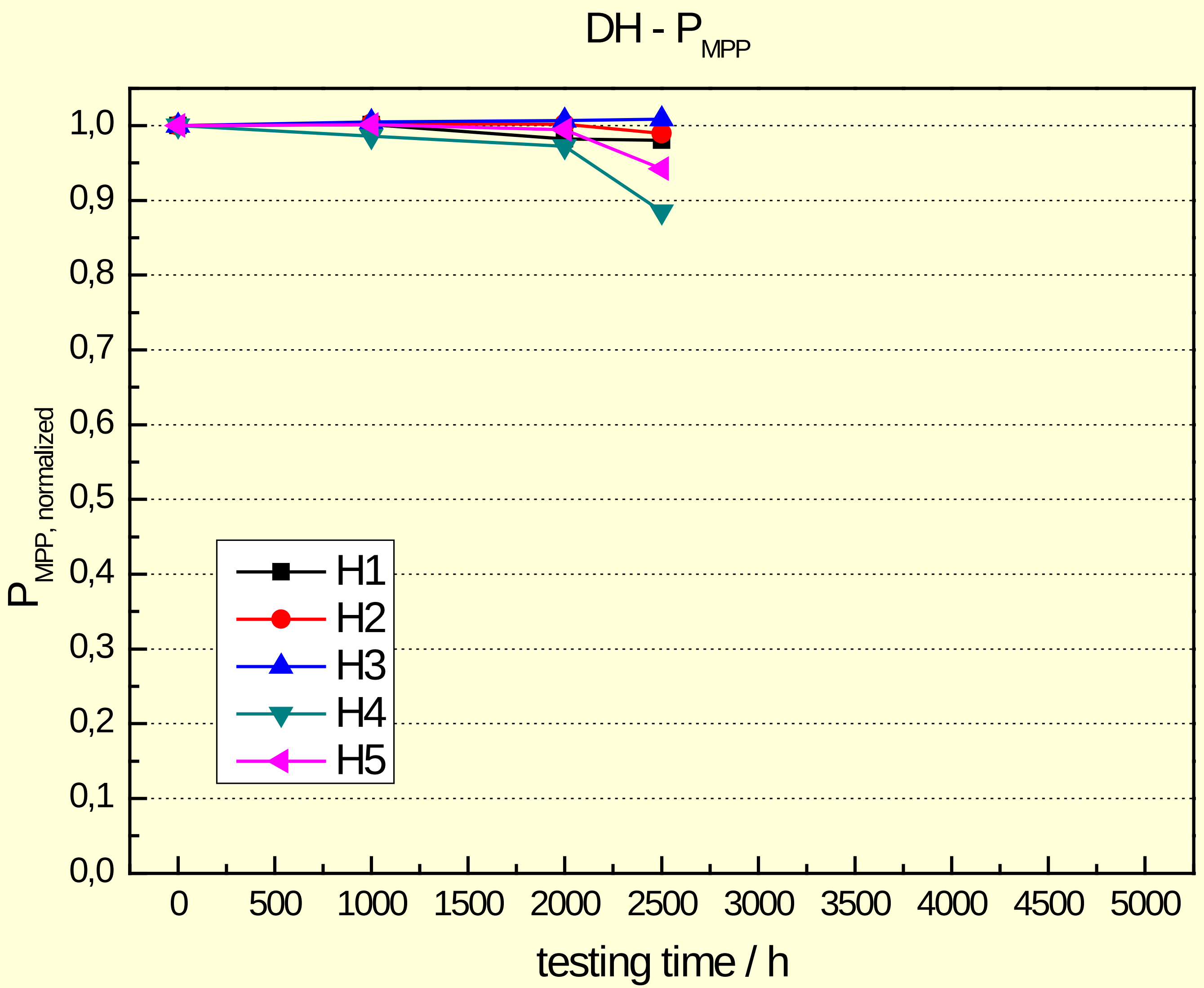
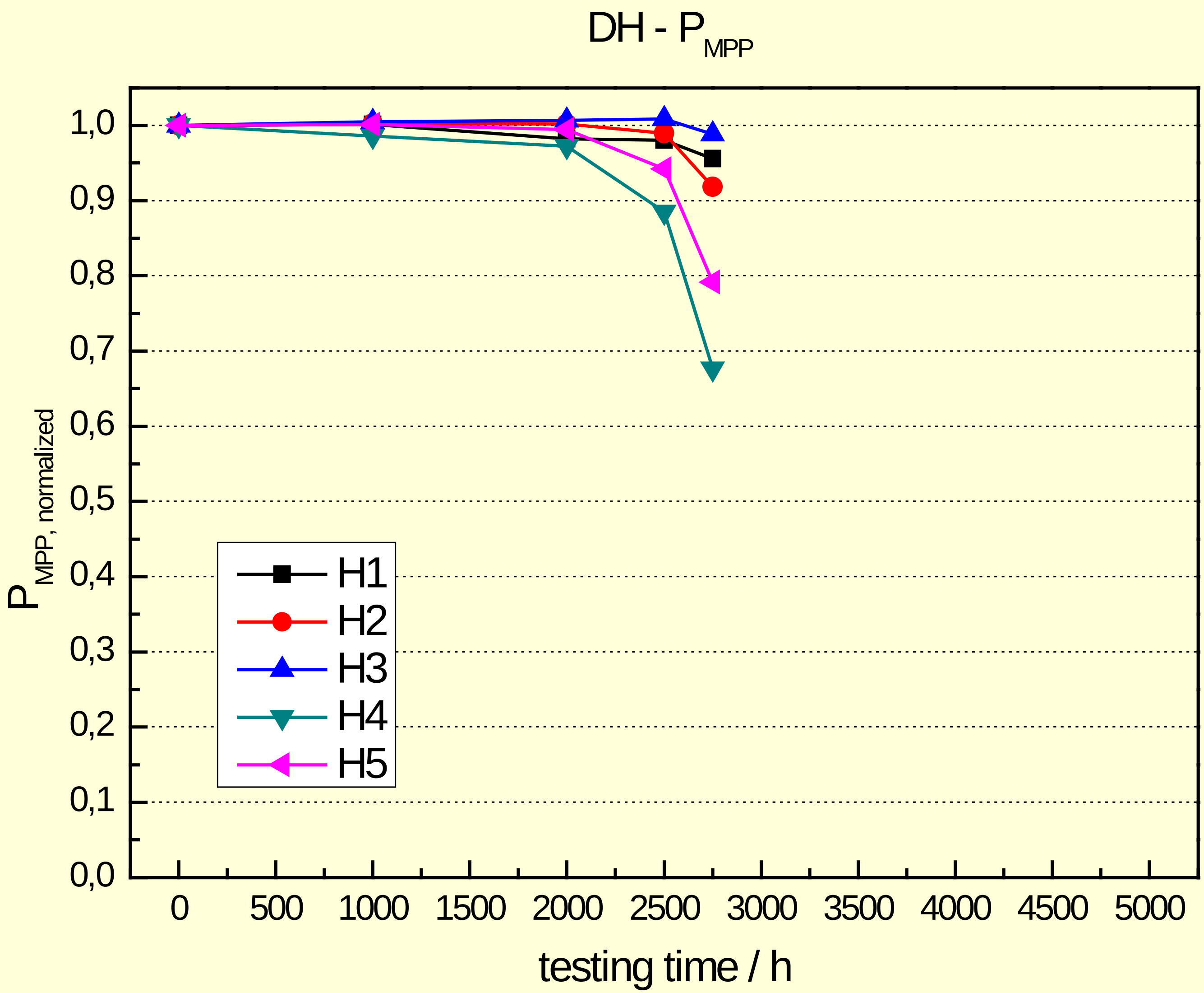
Evaluation of the parameters for time-transformation functions by ALT



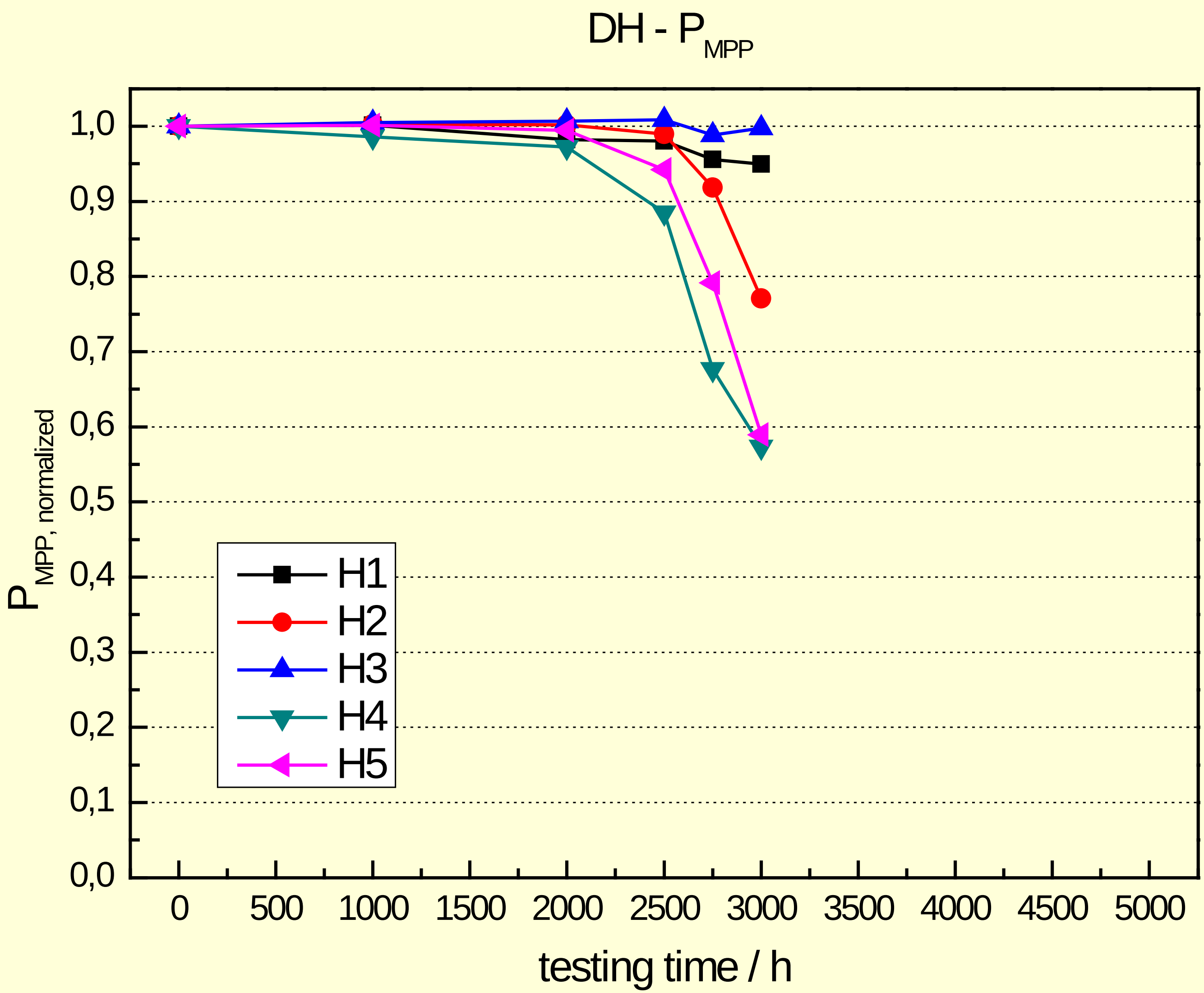
Evaluation of the parameters for time-transformation functions by ALT



Evaluation of the parameters for time-transformation functions by ALT



Evaluation of the parameters for time-transformation functions by ALT



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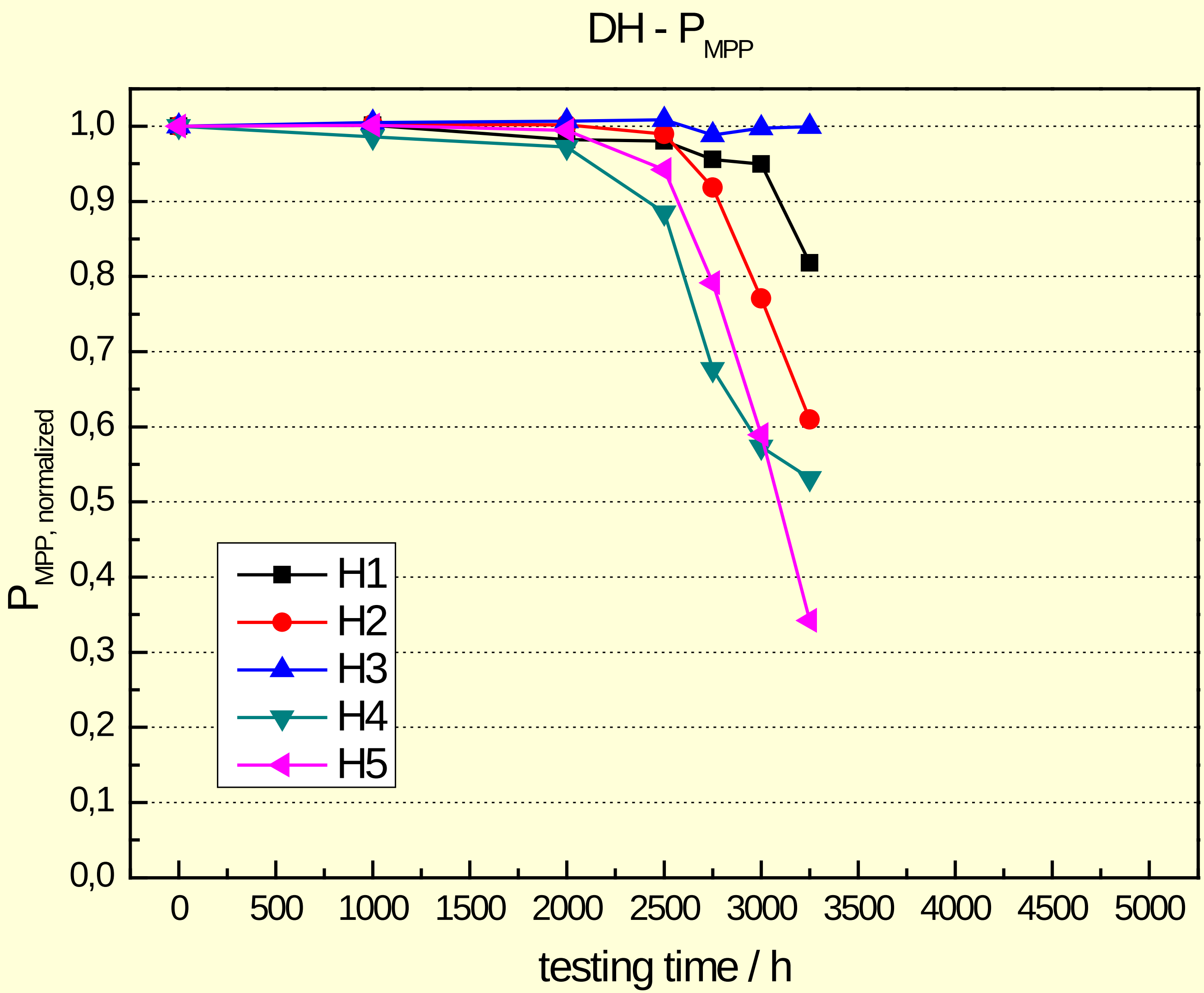
Evaluation of the parameters for time-transformation functions by ALT



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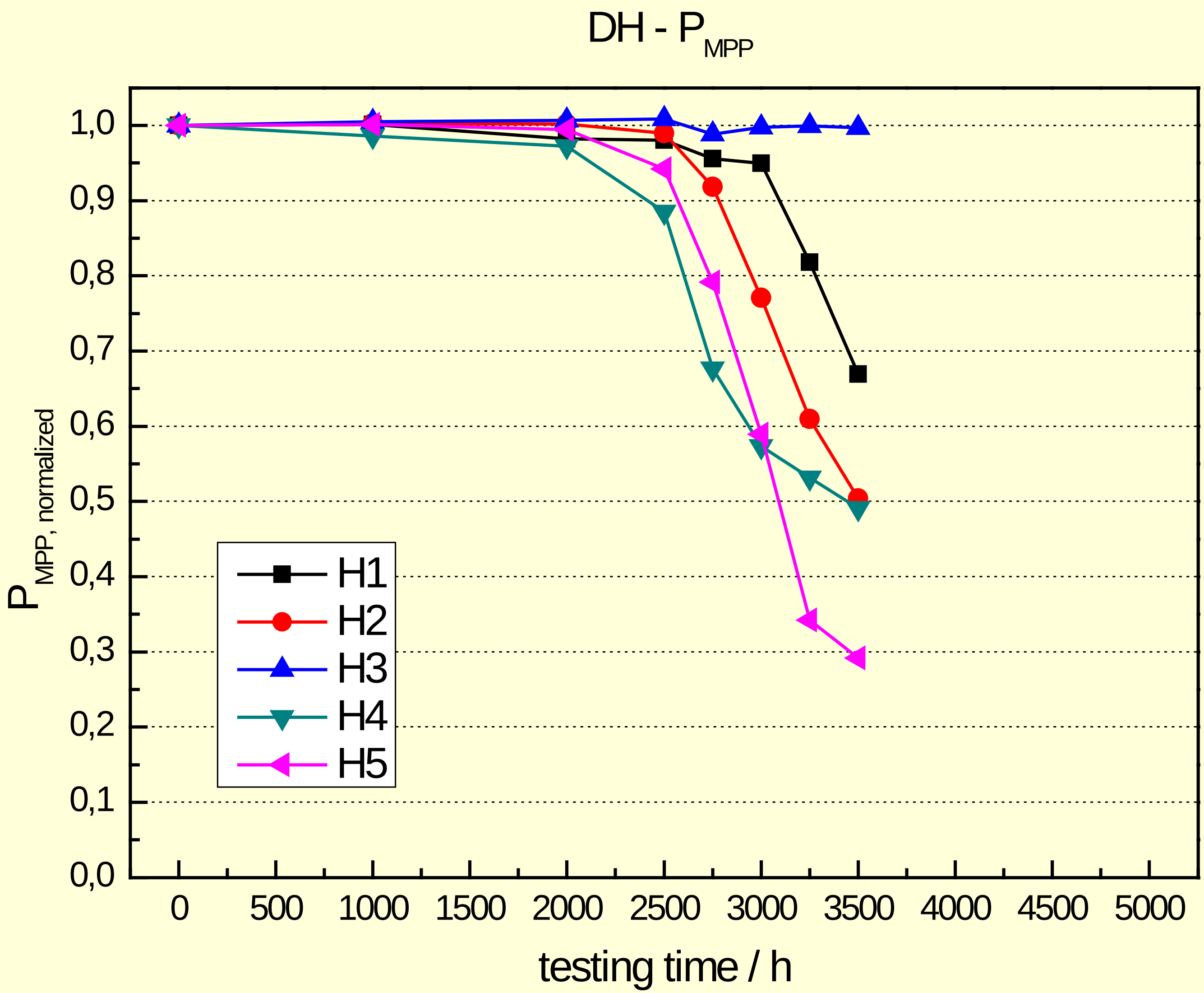
Evaluation of the parameters for time-transformation functions by ALT



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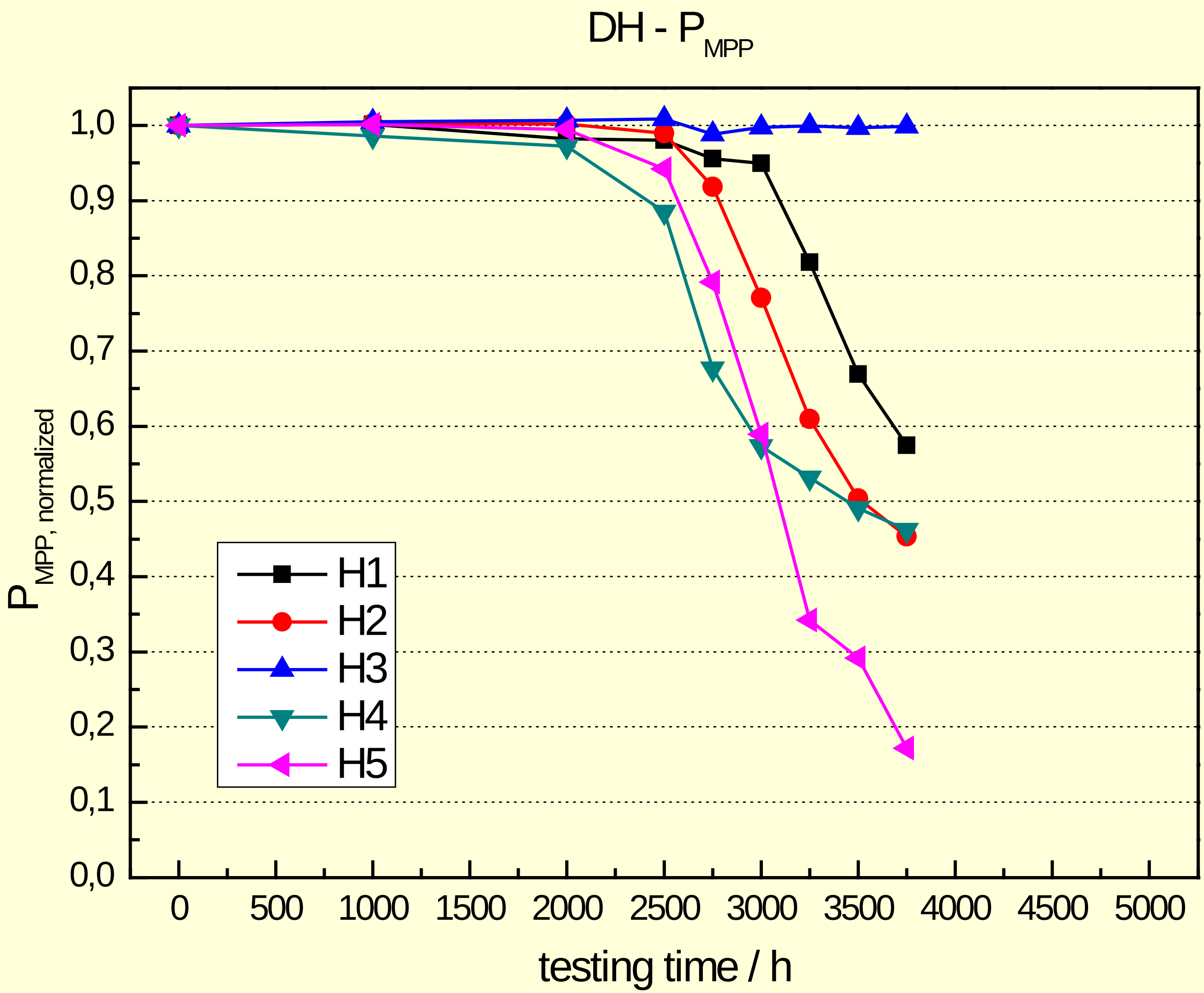
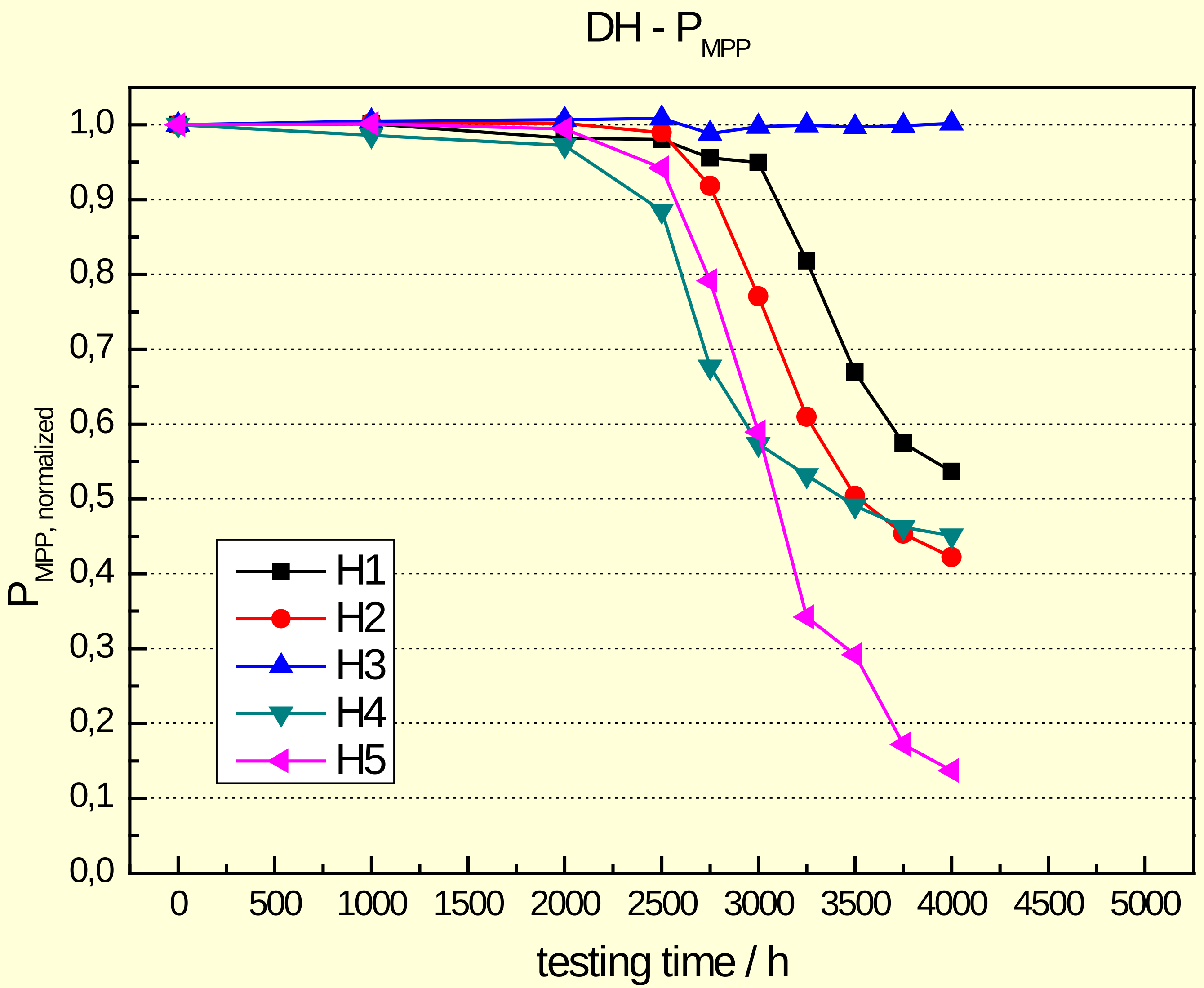
Evaluation of the parameters for time-transformation functions by ALT



Evaluation of the parameters for time-transformation functions by ALT



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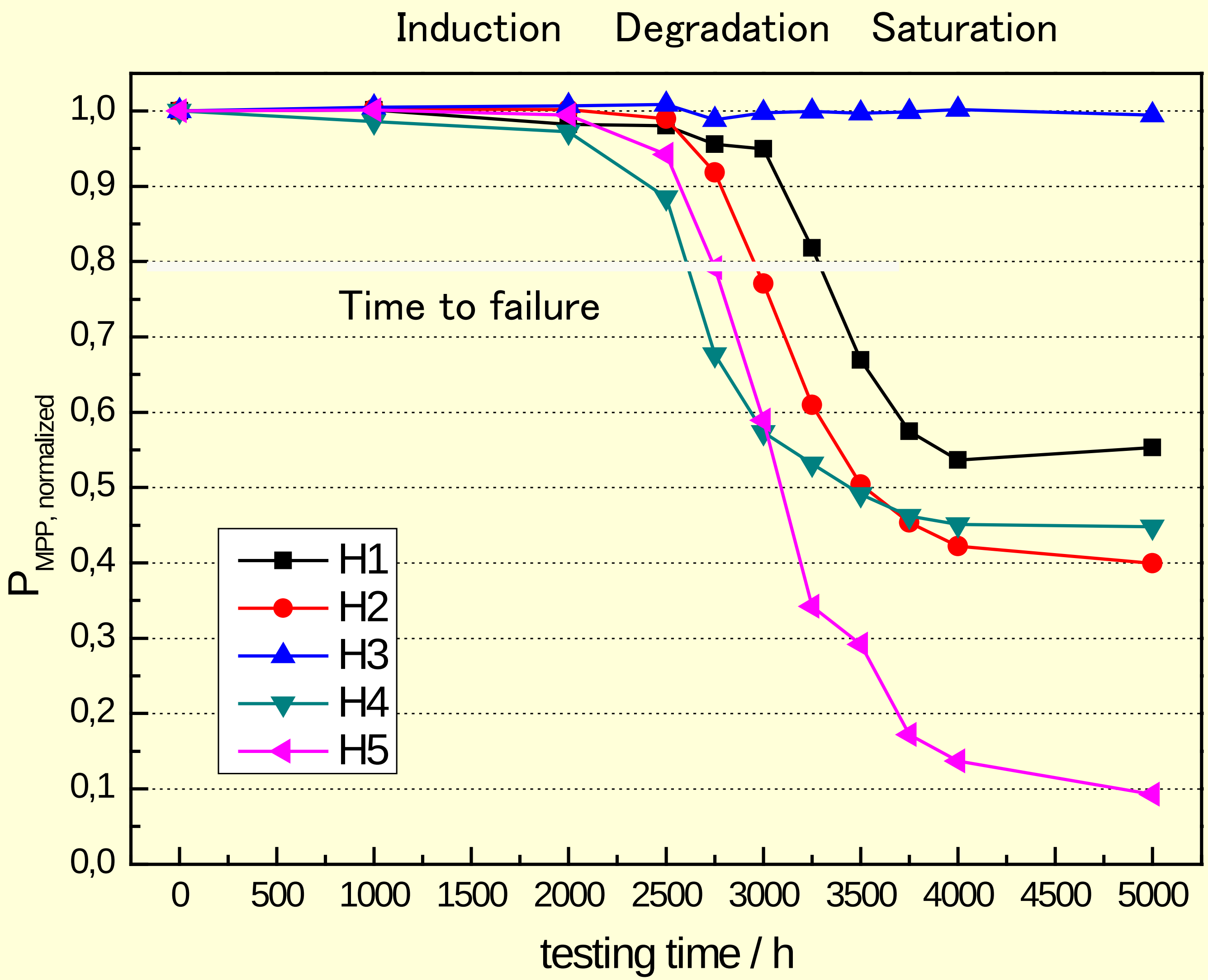

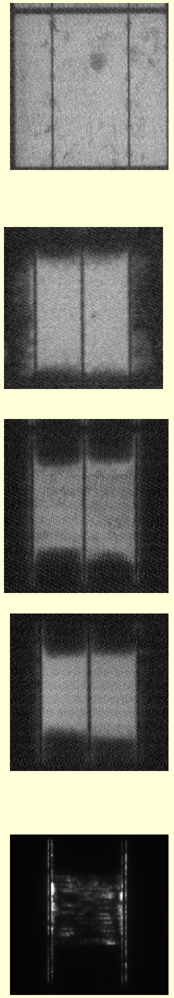

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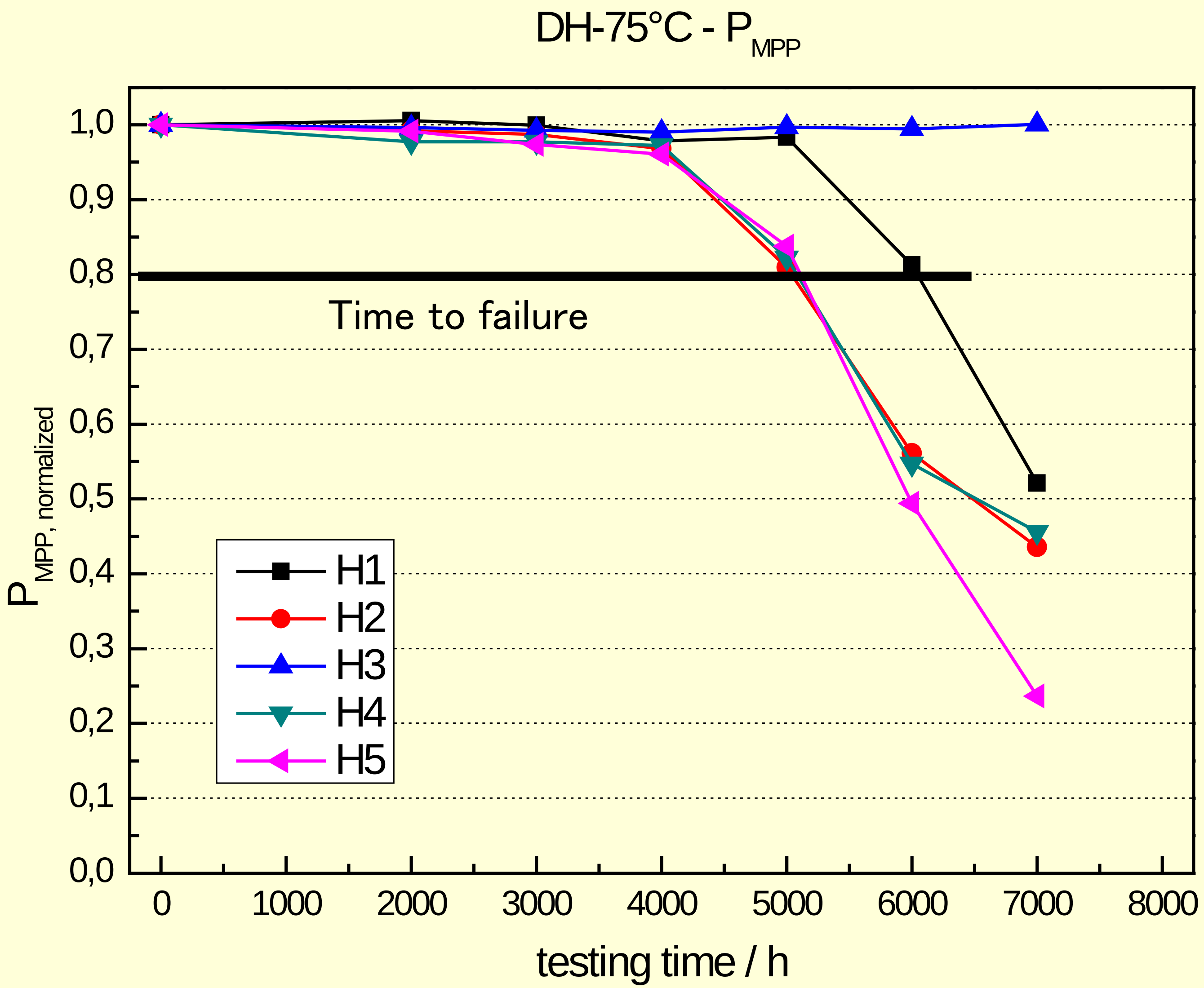
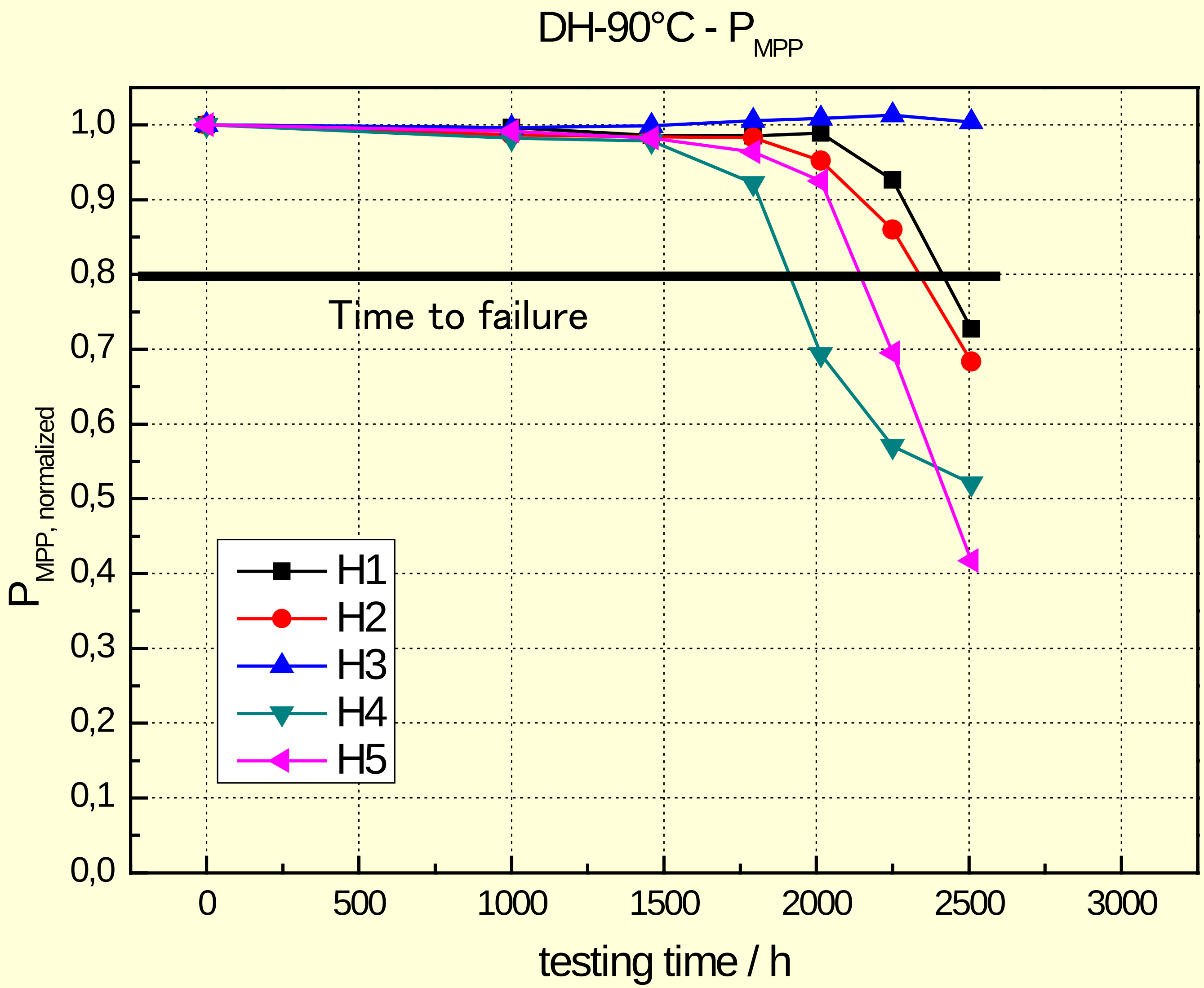


Evaluation of the parameters for time-transformation functions by ALT



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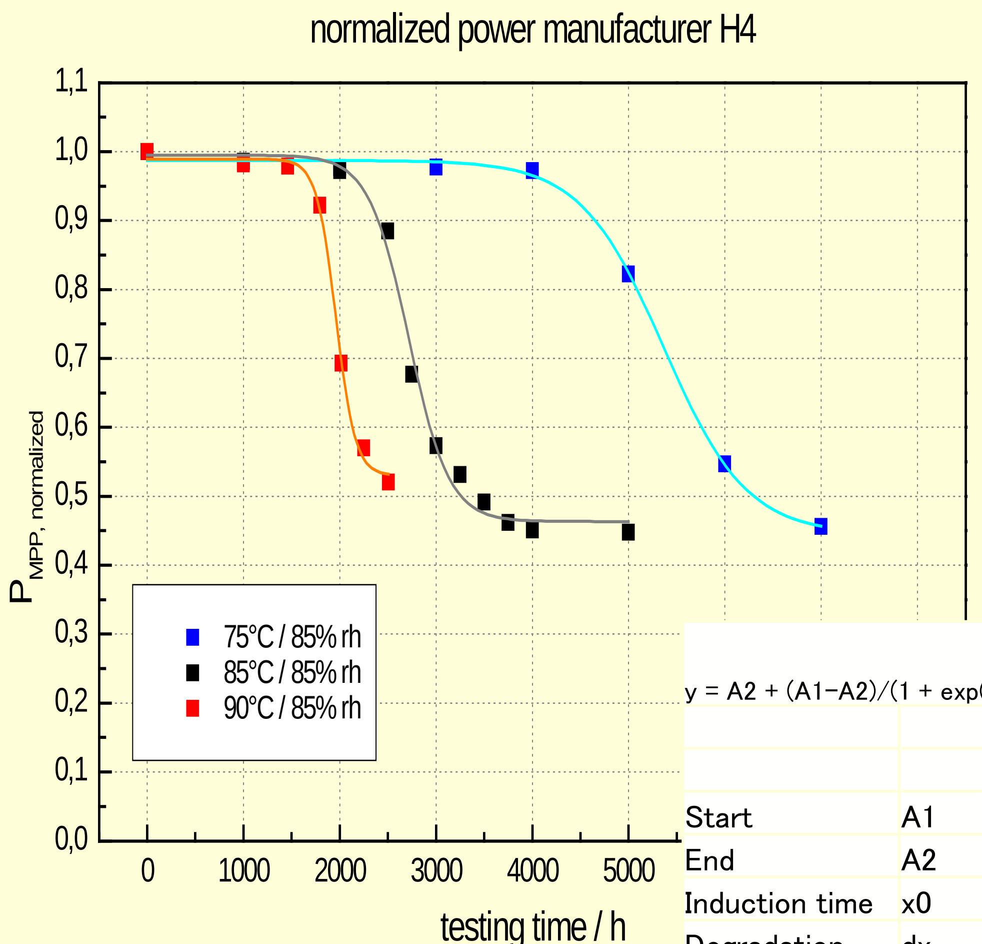
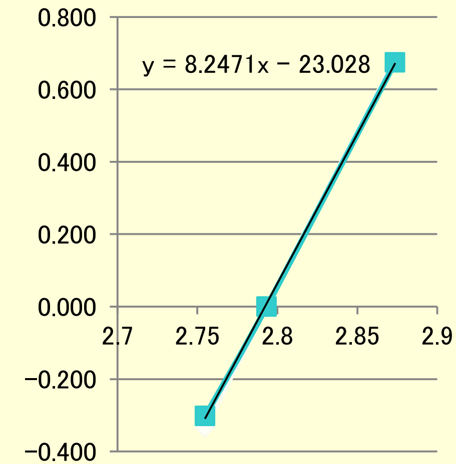
Evaluation of the parameters for time-transformation functions by ALT

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





Arrhenius−Plot:

Activation energy = 68.4 kJ/mol

y = A2 + (A1−A2)/(1 + exp((x−x0)/dx))

		75°		85°		90°	
		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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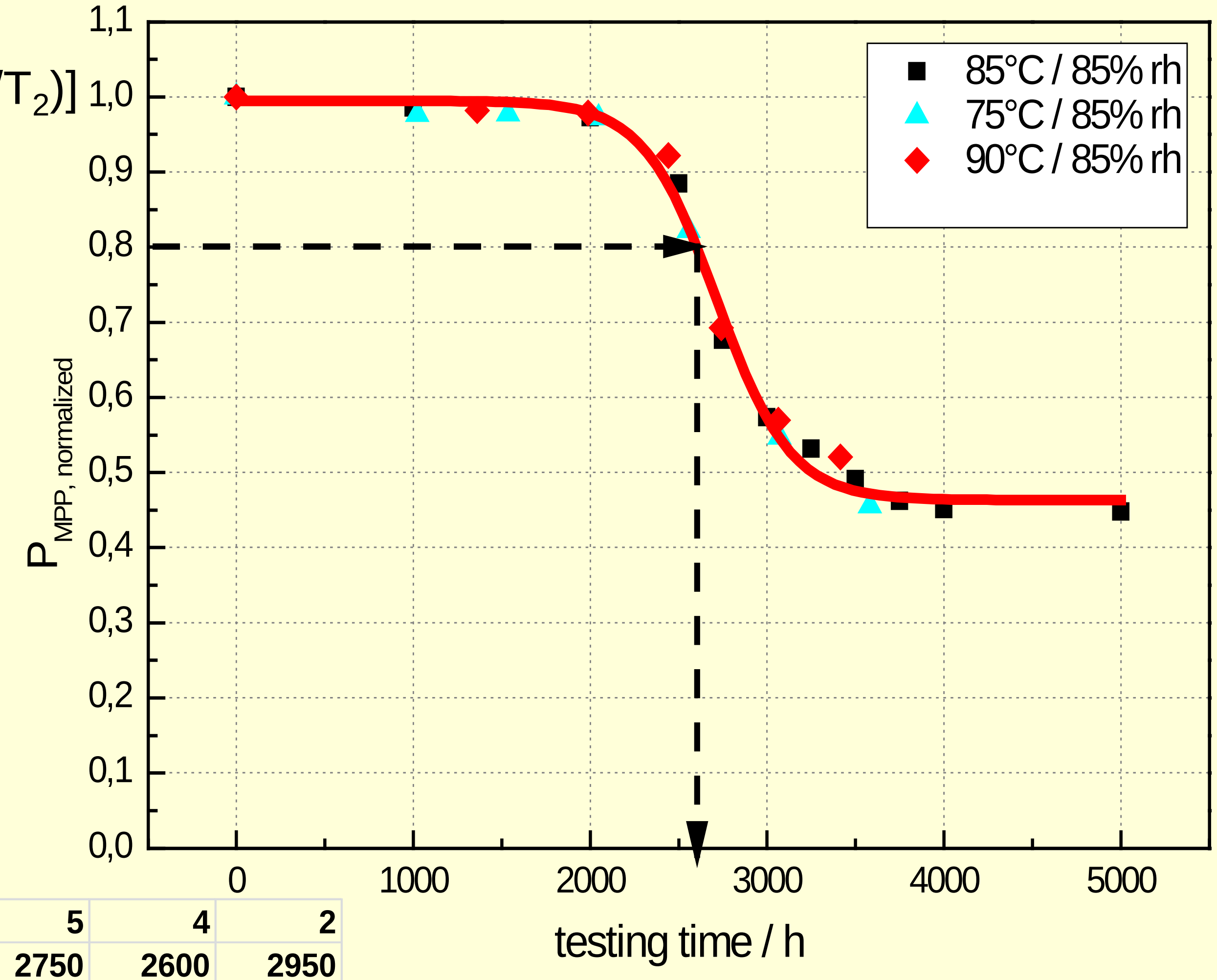
Evaluation of the parameters for time-transformation functions by ALT

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



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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Evaluation of the service life time in different climates

Activation energy is more important than time to failure

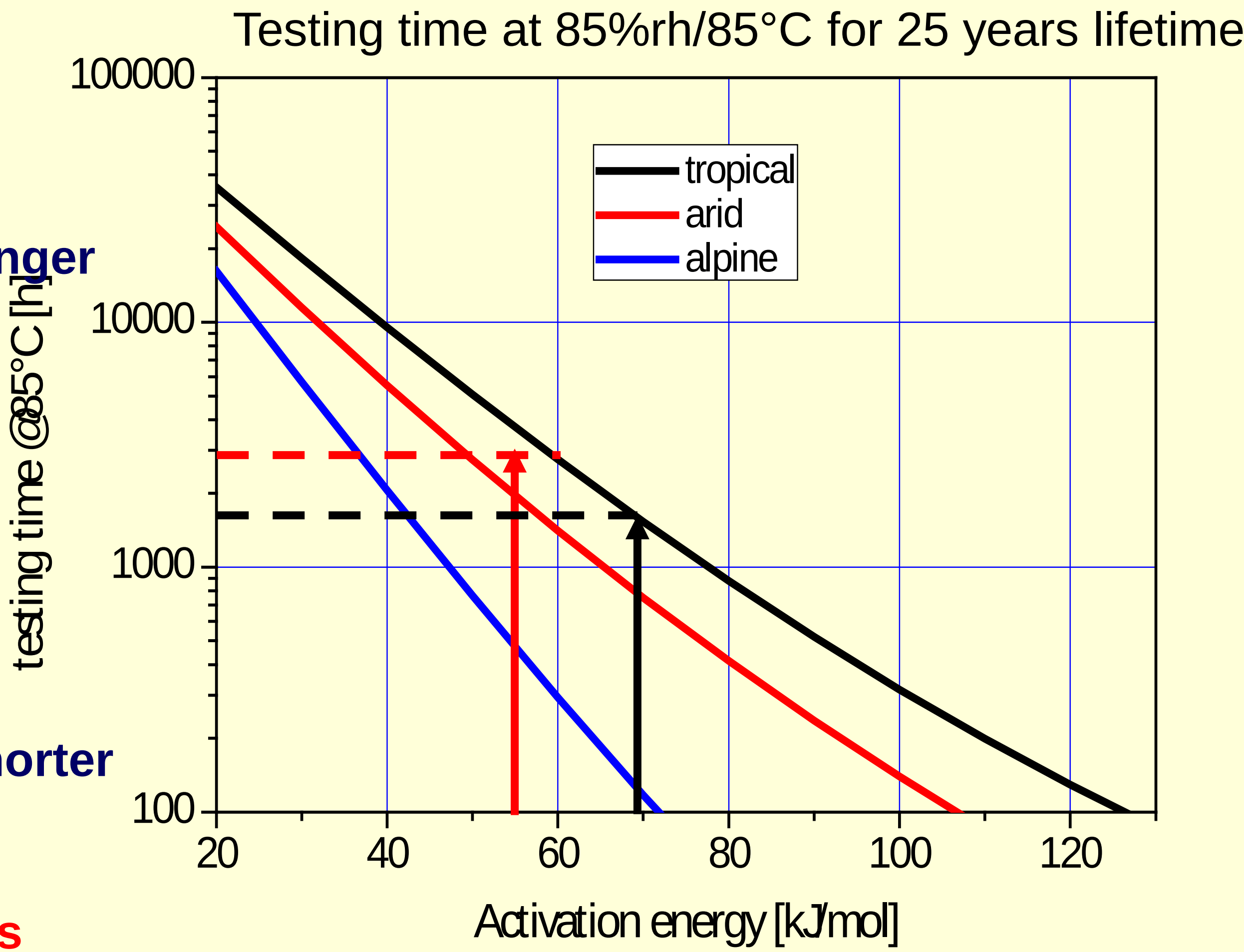
E_a = 70 kJ/mol

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

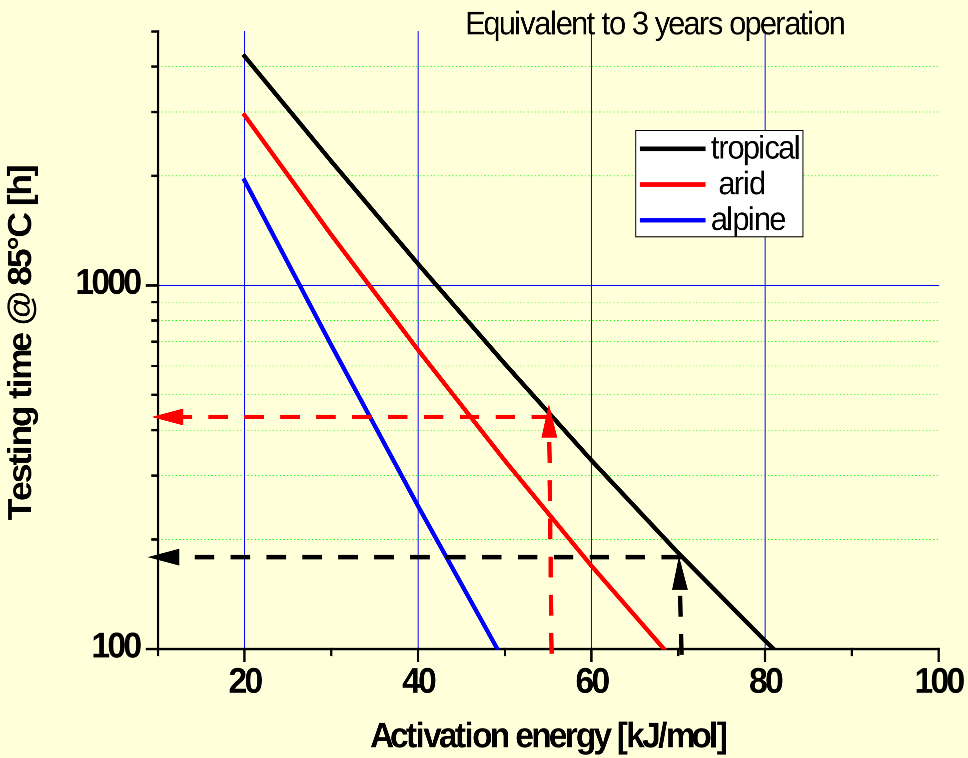
But good enough for deserts



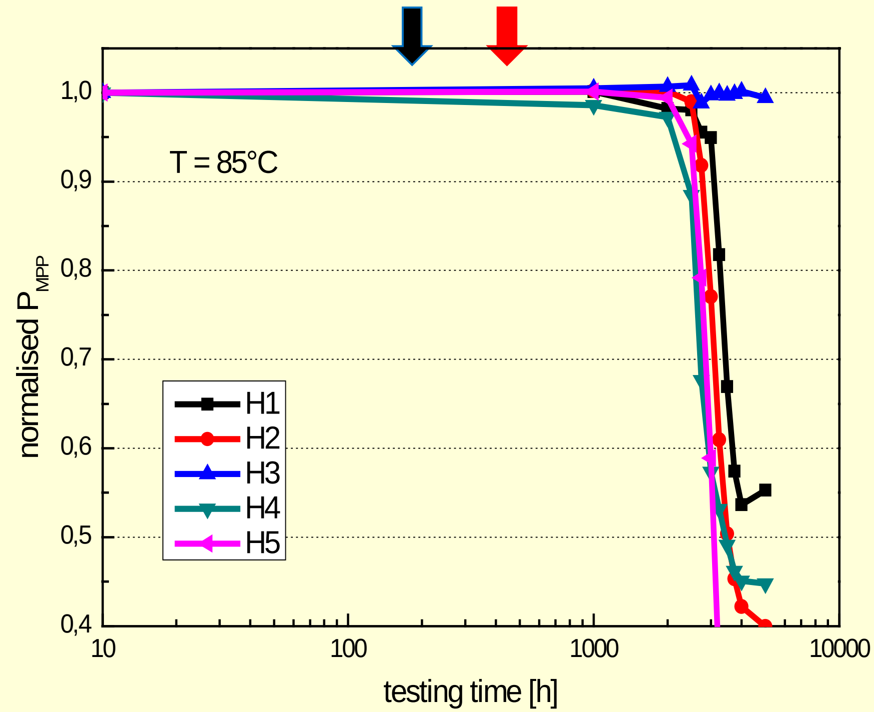
Modeling expected degradation for validation by outdoor exposure

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

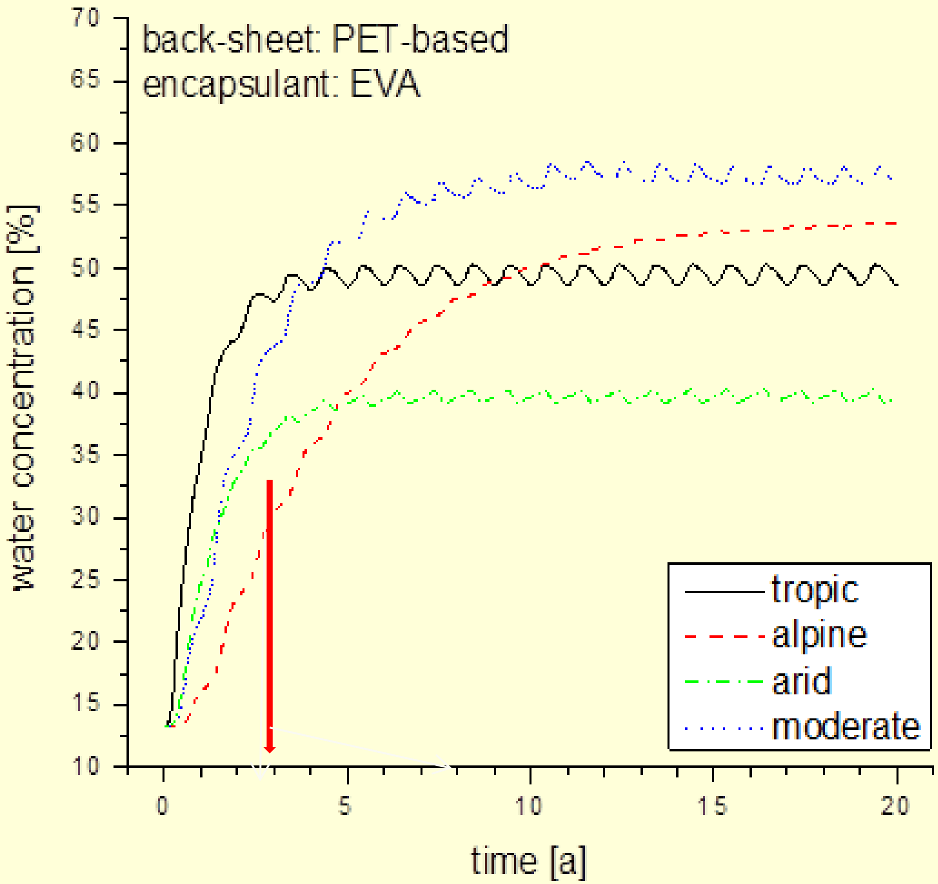


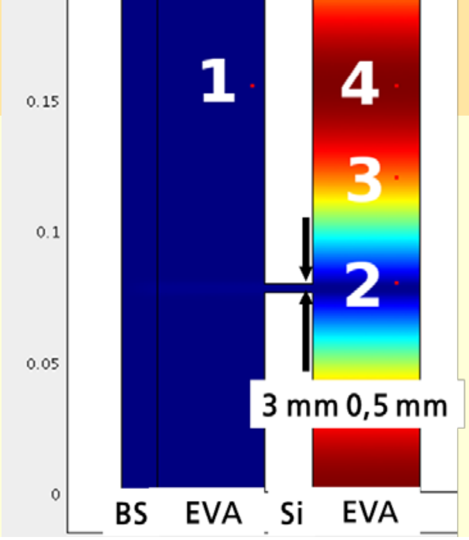
200h – 450h

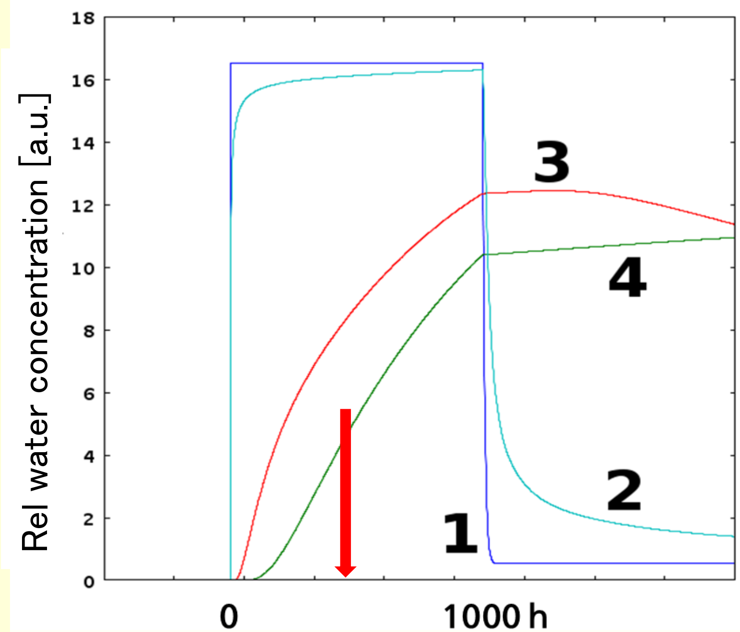


Modeling micro-climatic stress factors

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.

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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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How can we detect degradation processes in the initial state during the induction period when no changes in the electrical properties can be found?

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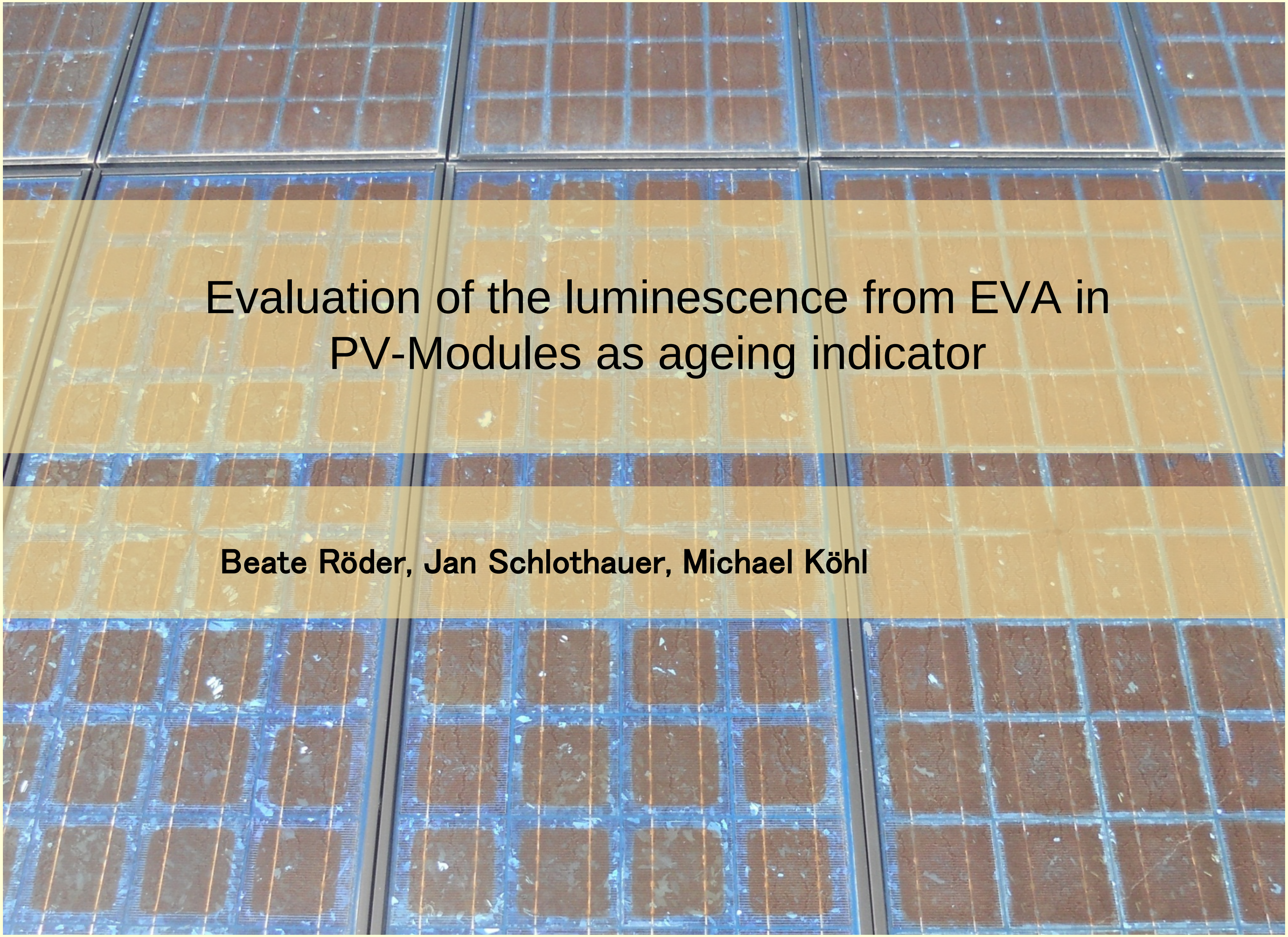

Evaluation of the luminescence from EVA in PV-Modules as ageing indicator

Beate Röder, Jan Schlothauer, Michael Köhl

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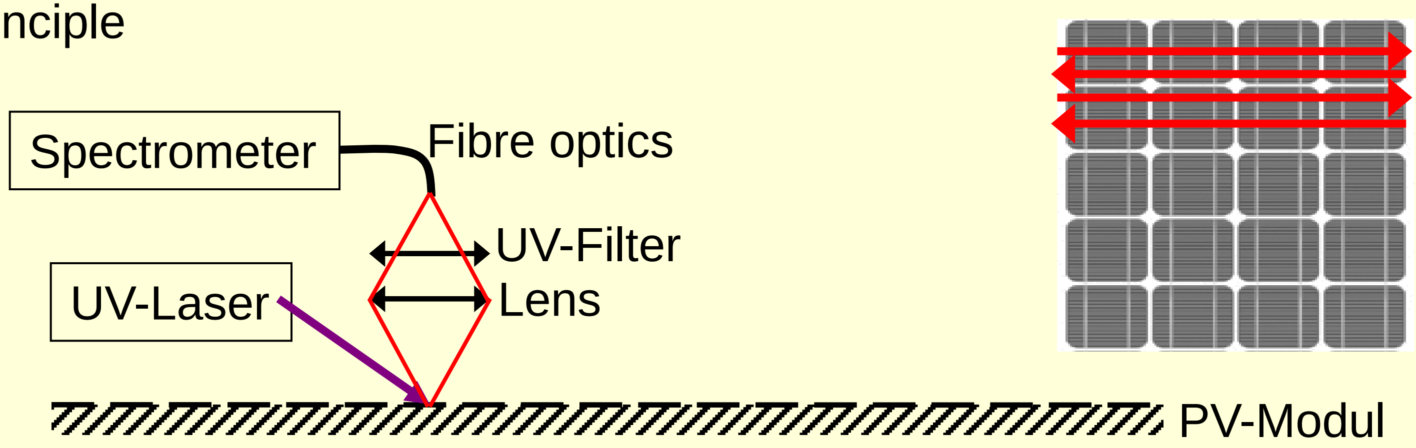
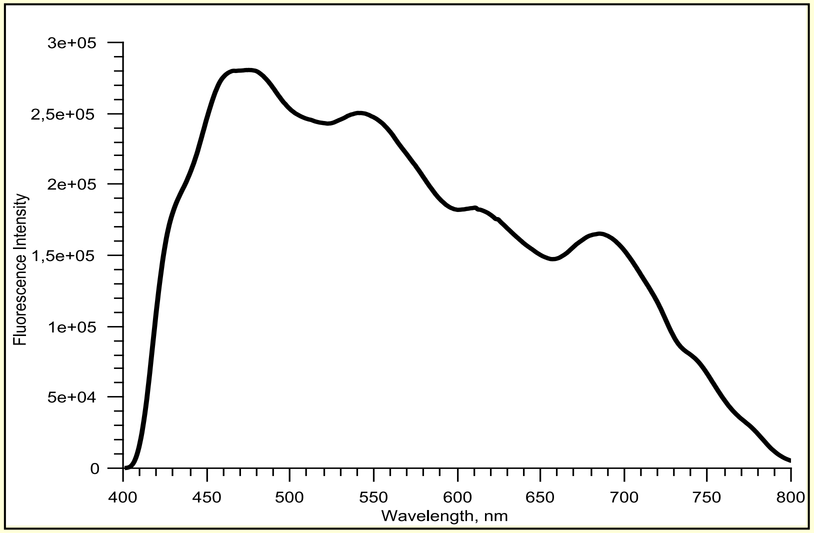
Space-resolved measurements on PV-Modules

Principle



Spectrally and laterally resolved detection of fluorescence via scanning procedure:

The scan-head moves with constant velocity, contineously taking the spectra.



Luminescence spectrum

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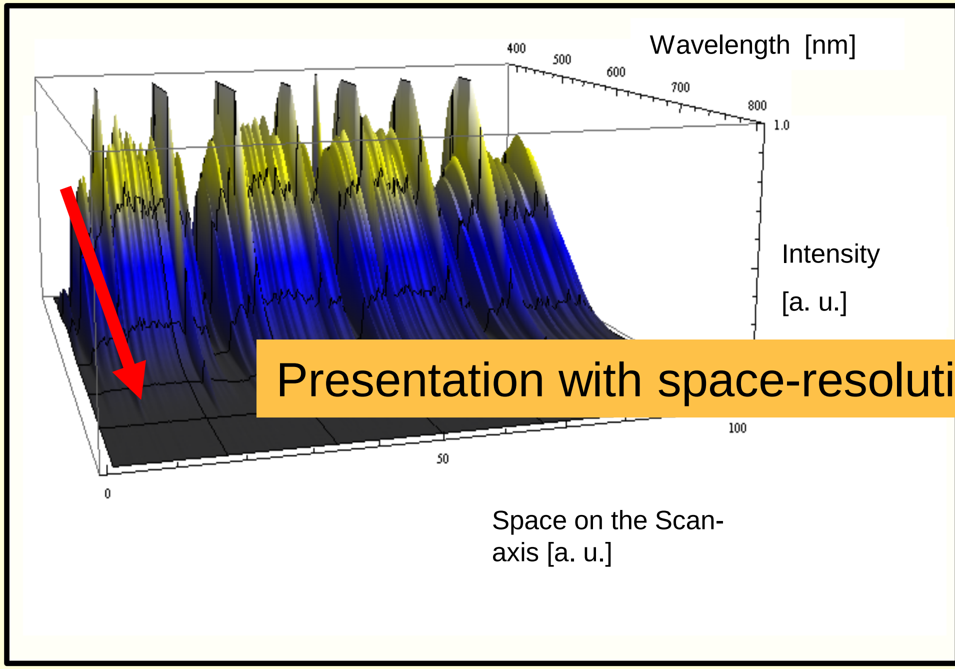
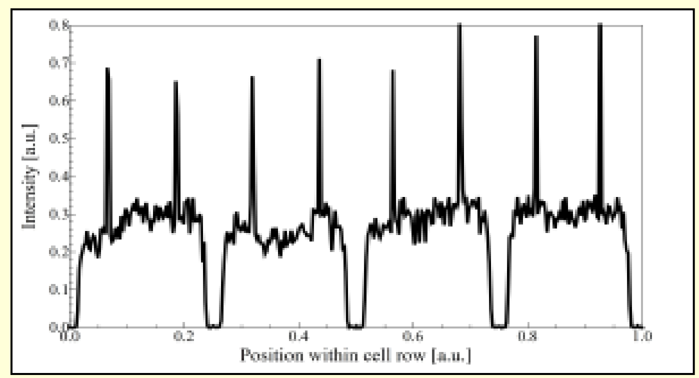
Data collection

First step of analysis: integration of fluorescence spectra
and graphical presentation of the location dependent total intensity



Presentation with space-resolution via integration of the spectra

Line-Scan – with spectral information



Line-Scan – Total intensity

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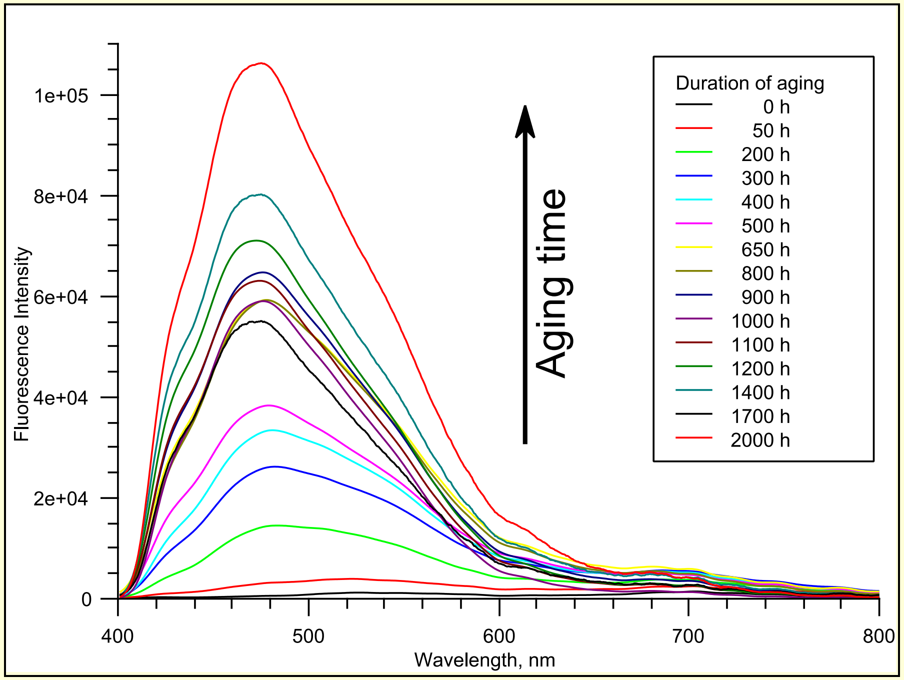
Fluorescence and ageing

Fluorescence after accelerated ageing e.g. DH (85°C/ 85% rh.): (Minimodul: Glass/EVA/Si-cell/EVA/back-sheet)



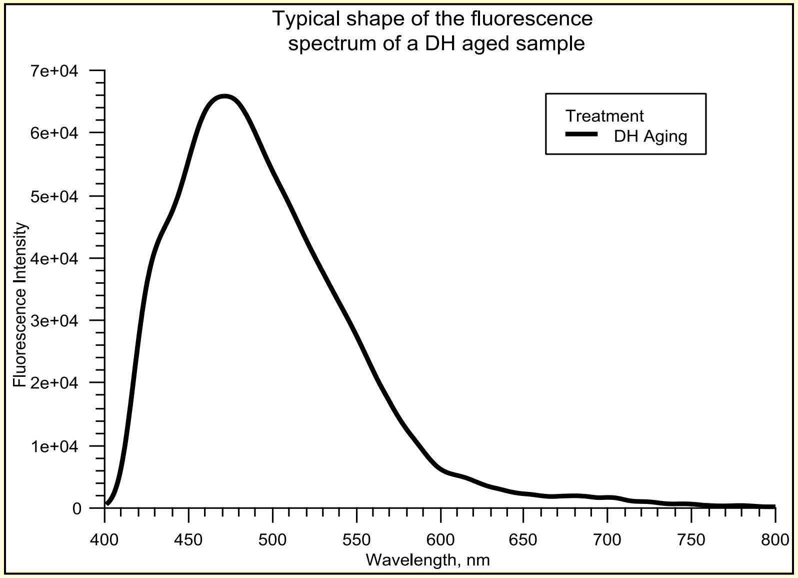
Fluorescence intensity increases monotonically with ageing

Spectral differences can be observed for different module types and degradation parameters

SPIE 2008 70480F
SPIE 2010 7773-11,7773-19

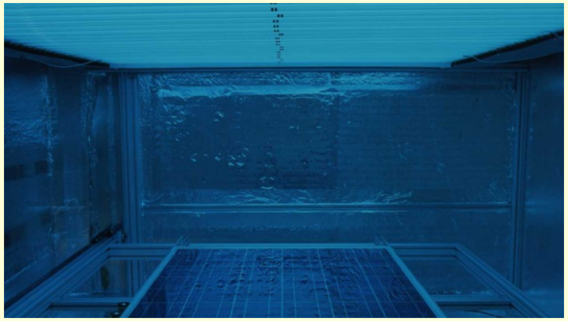
Influence of the degradation factor on the fluorescence spectrum

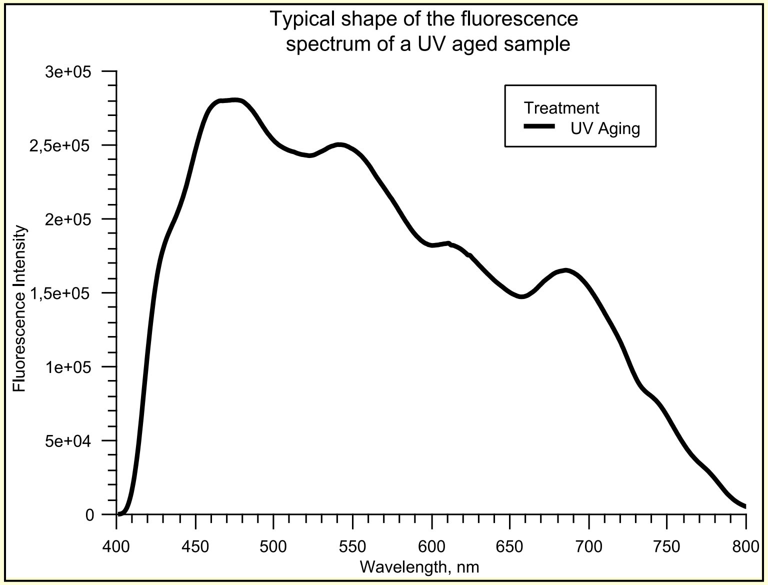
DH (85/85)



Emission from 400nm to 600nm , one dominant peak around 470nm

UV





Emission from 400nm to 800nm, several spectral bands

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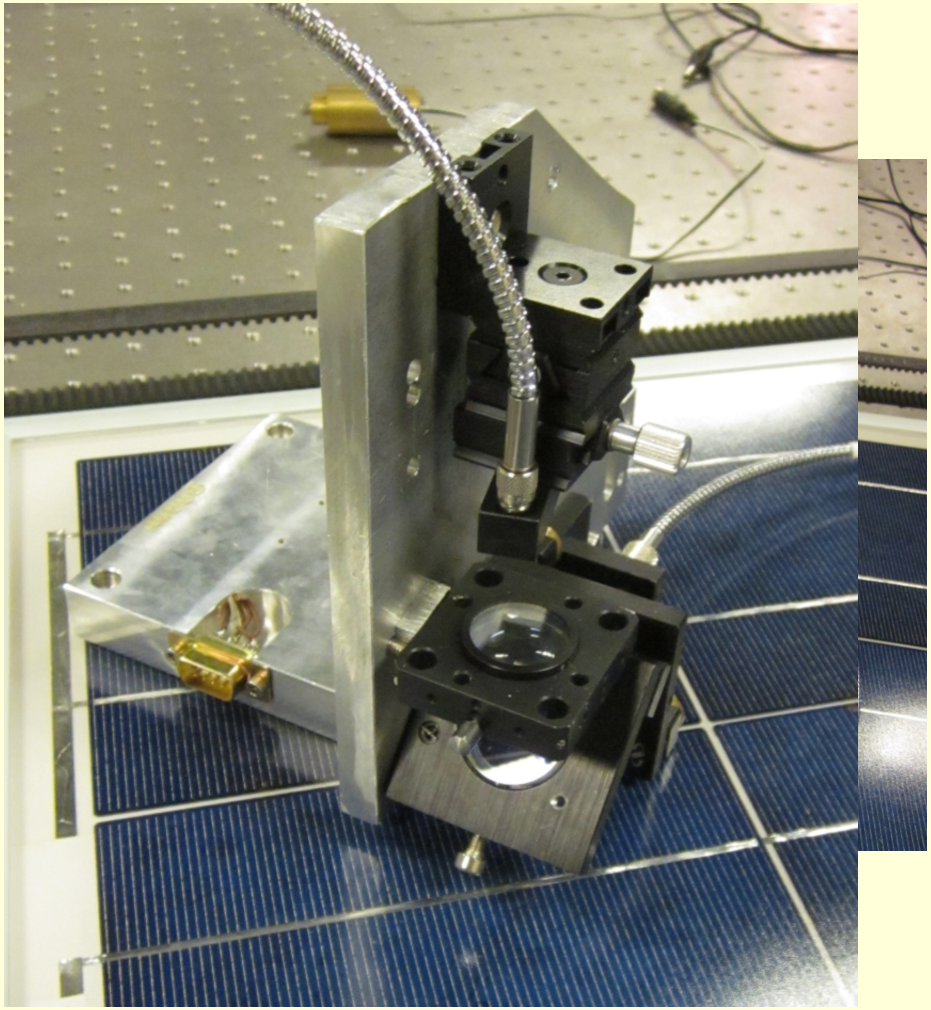
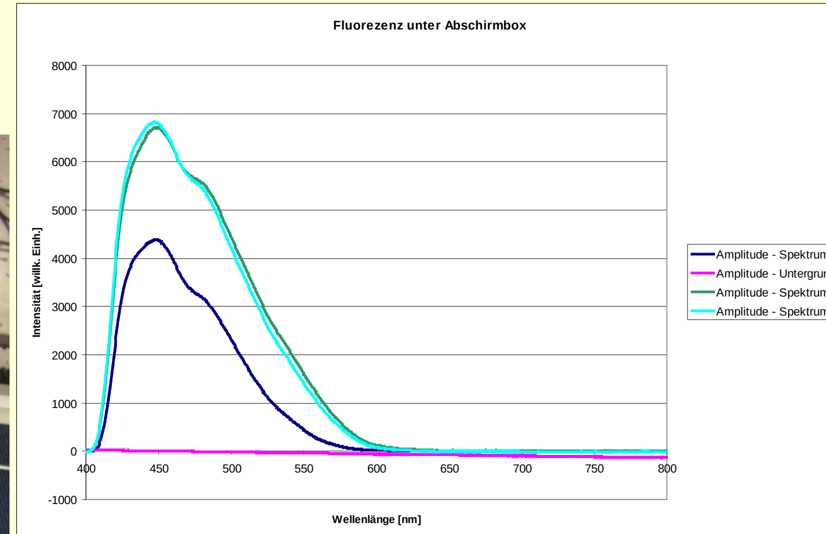
Set up for imaging fluorescence of commercially available PV-Modules





Already minimal light protection guarantees reproducible measurements

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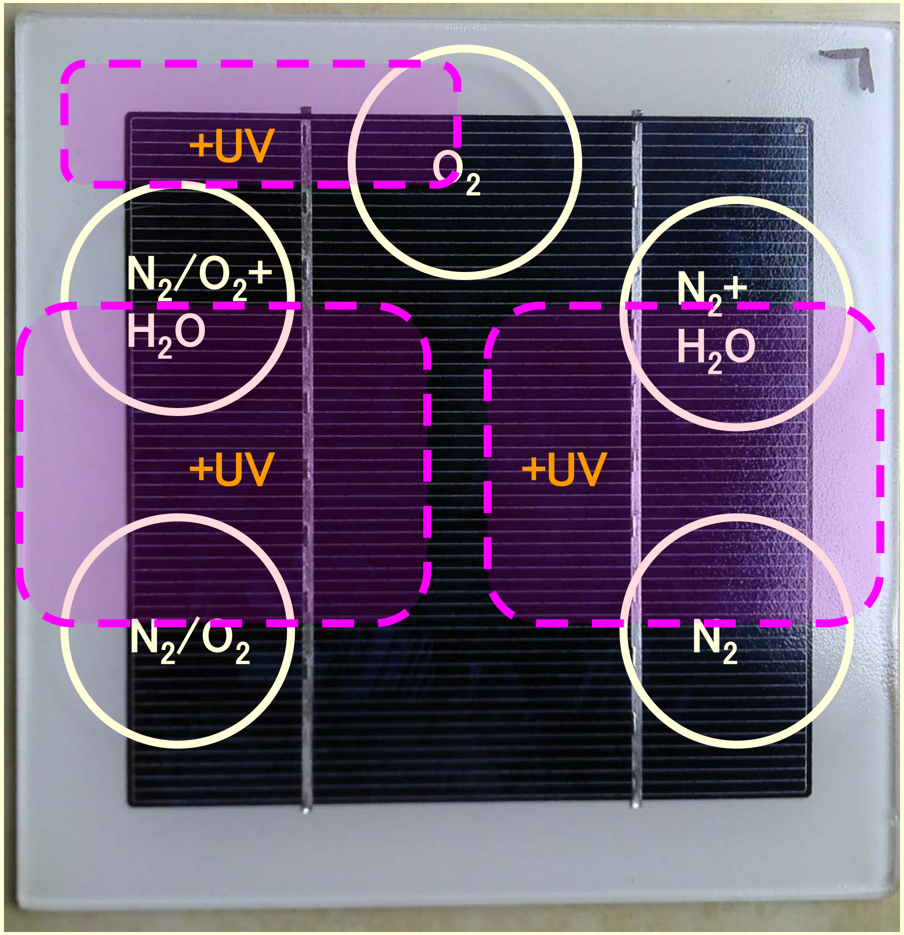
Multi-Ageing Chamber



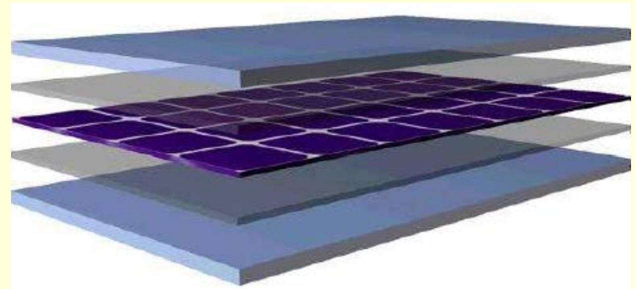
Simultaneous application of different degradation factors on one sample.

Fluorescence Measurements on the sample after different ageing times.

Different fluorescence intensity and spectra over ageing time for the diffrenet degradaton factors

Samples

c–Si– PV–Modules from
7 companies
(data anonymized)



4 different weathering sites:

Moderate,
Germany:Cologne

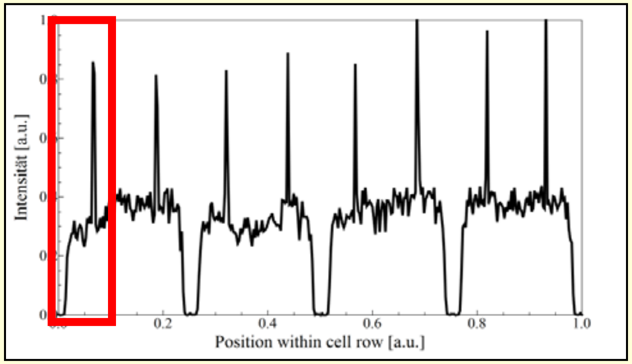
Alpin, Germany:
Zugspitze, 2650 m

Desert, Negev
Israel

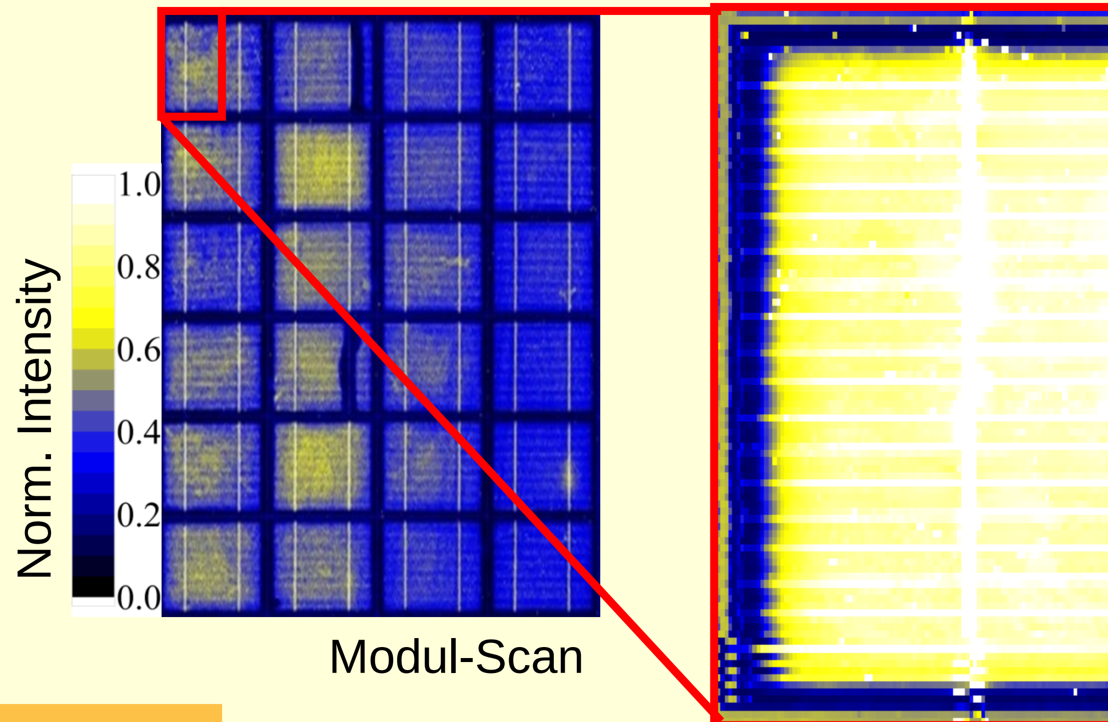
Tropic, Indonesia

2 years outdoor weathering

Local effects: Bleaching caused by diffusion processes



Line-Scan



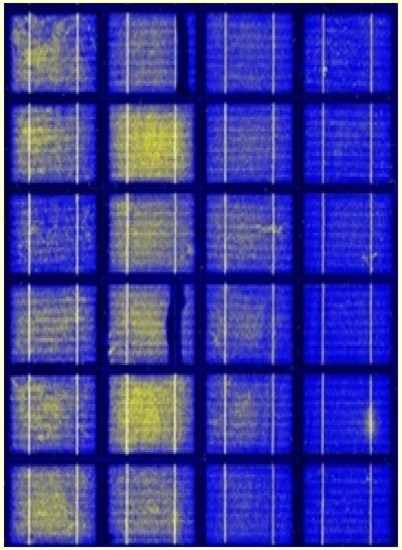
Modul-Scan

Zoom-in

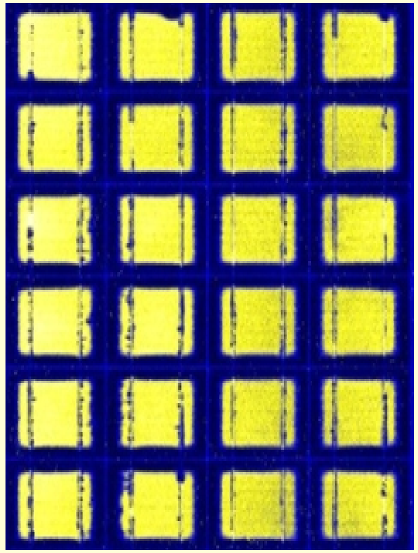
The permeable back sheet allows the ingress of oxygen causing bleaching of the fluorophores around the cell edges resulting in lowered fluorescence

Influence of different climatic conditions

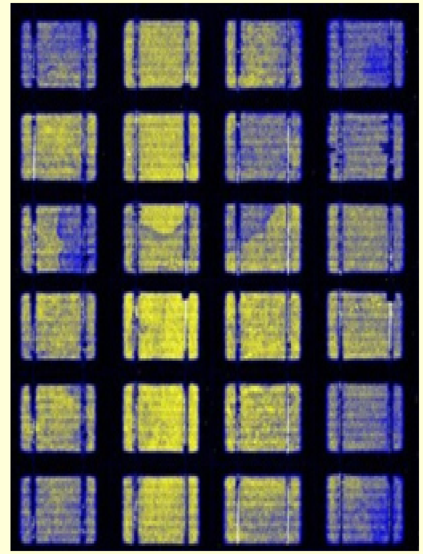
Zugspitze



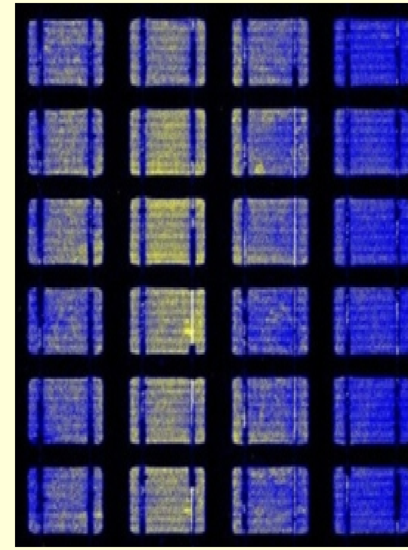
Cologne



Israel



Indonesia



PV modules from one company, measurement after 2 years outdoor weathering

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J. Schlothauer, et. Al., *Solar Energy Materials and Solar Cells* vol. 102 July, 2012. p. 75-85

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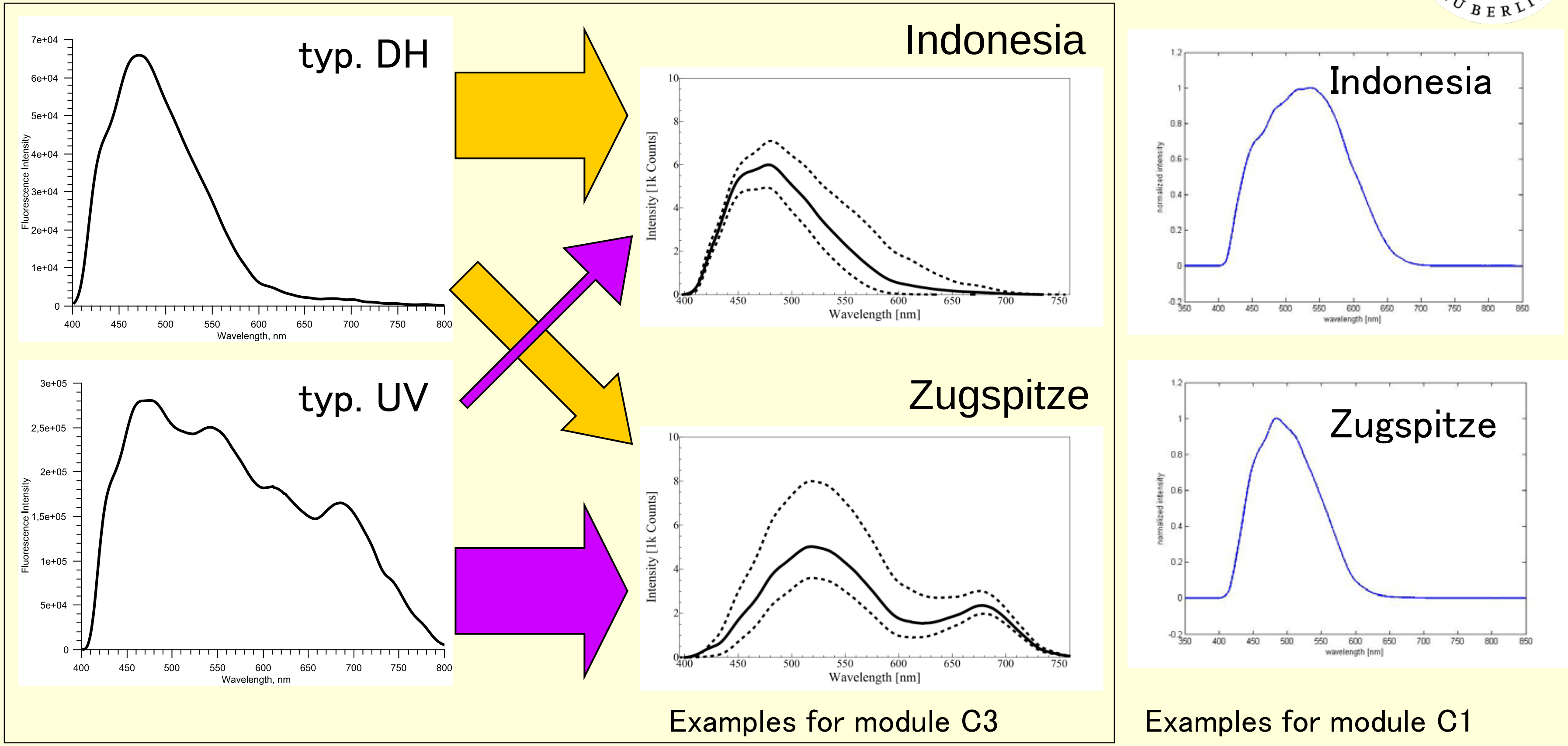
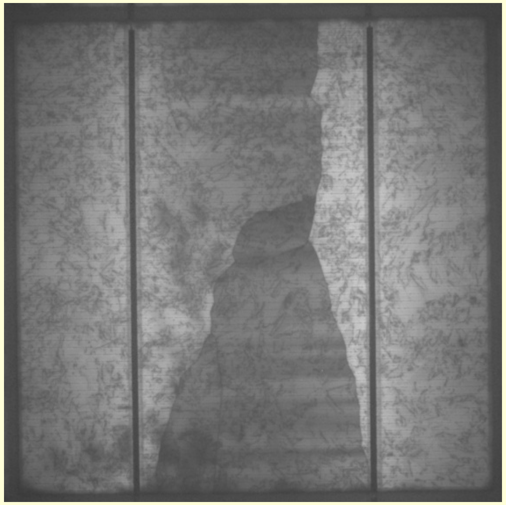
Spectral Information

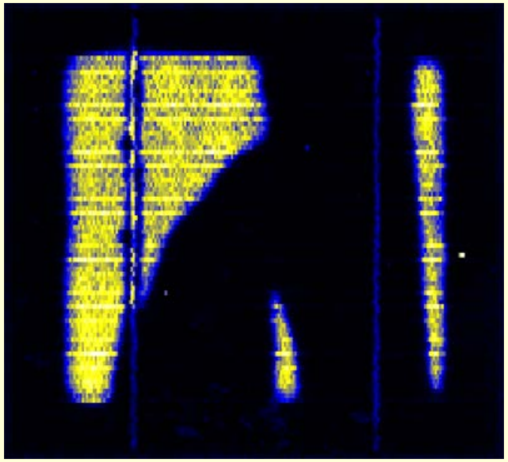


Information is more complex than for single degradation factor (UV / DH) ageing
But clear spectral differences can be observed

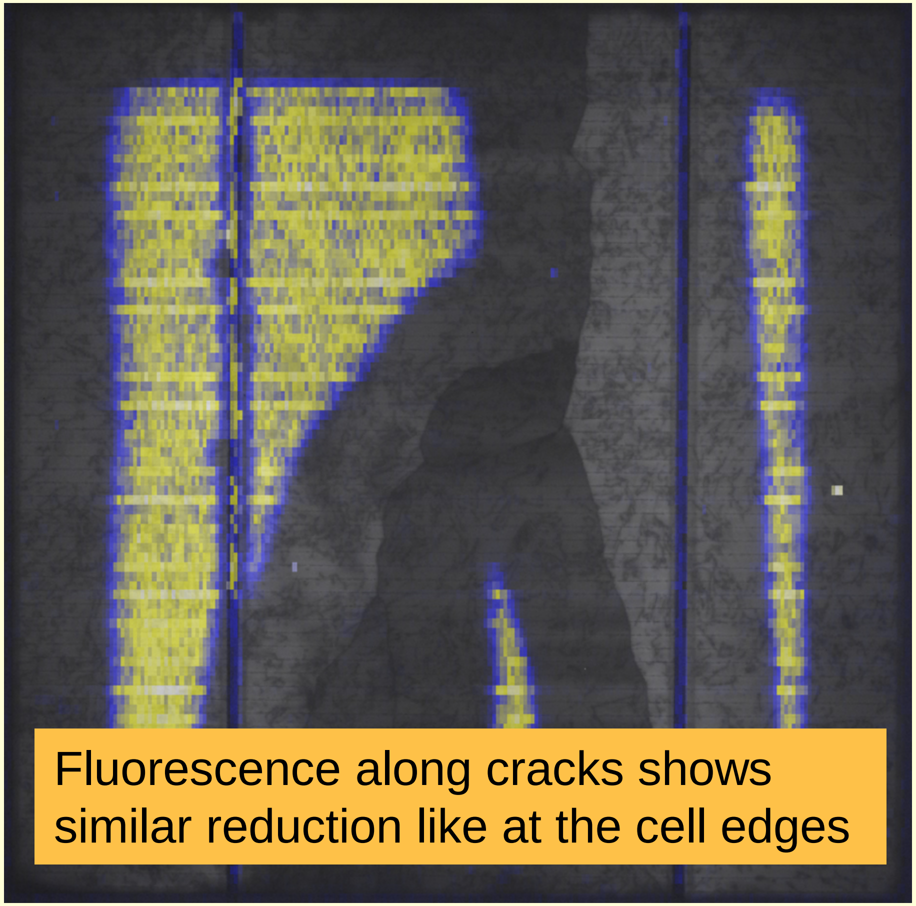
Influence of cracks on the fluorescence signal

Electroluminescence image (EL)





Fluorescence intensity distribution (FL)



Overlay of EL and FL

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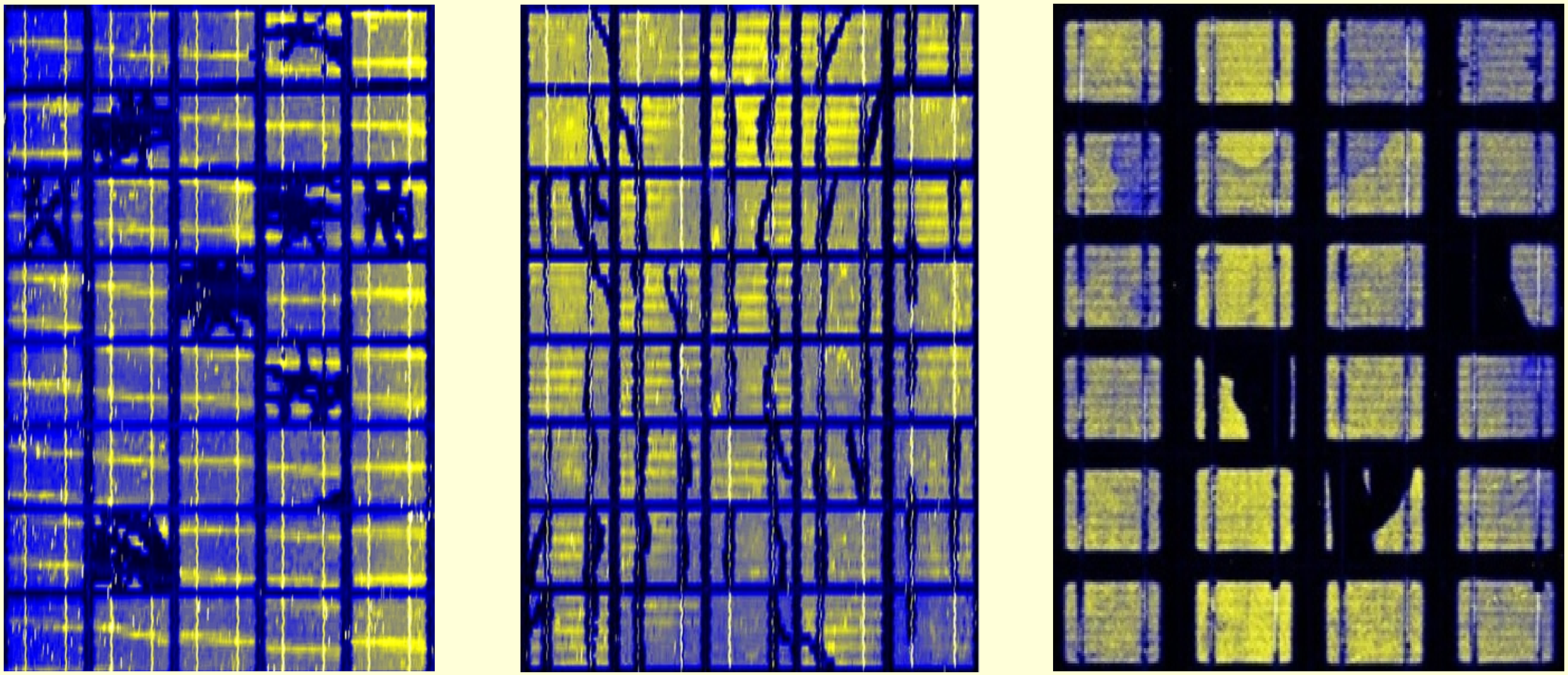
Examples of different kinds of damages



Different c-Si module types and weathering sites,
measurement after 2 years outdoor weathering

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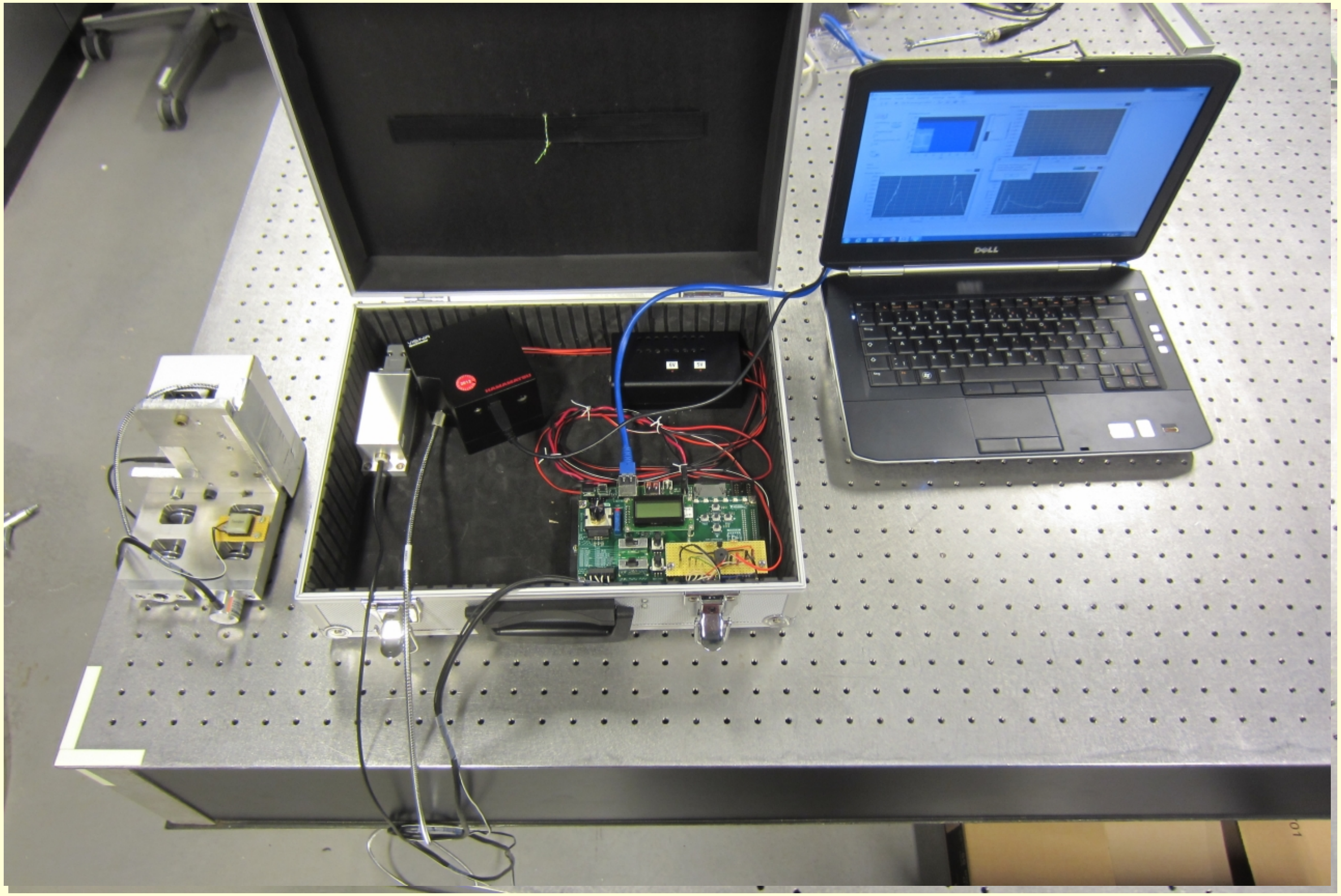
Field inspection set up



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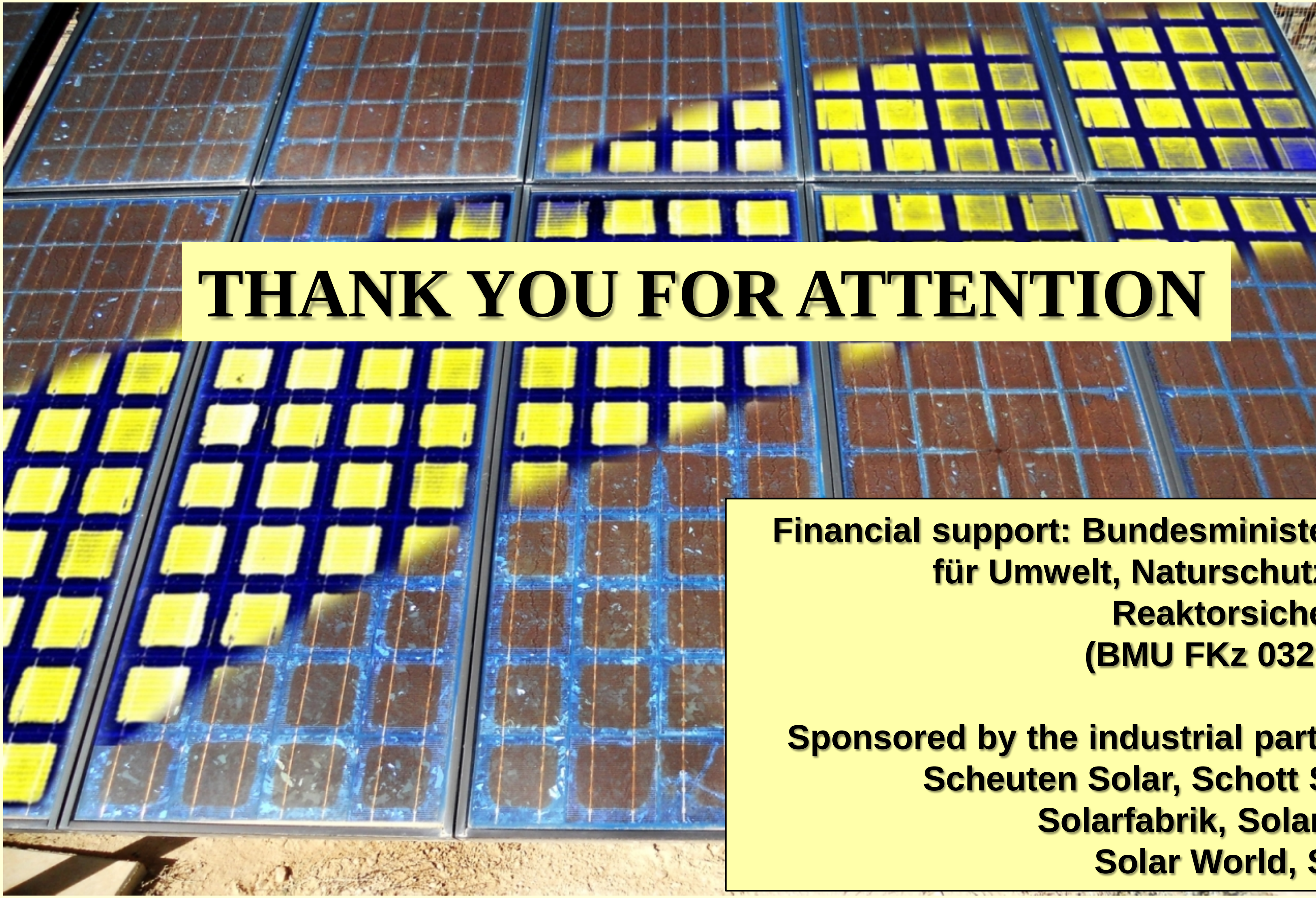
Conclusion and outlook

- Fluorescence intensity is an indicator for ageing time indoor and outdoor
- In PV modules the fluorescence is distributed inhomogeneously
- Diffusion processes (mostly O_2) enable destruction of chromphores in the polymer resulting in decreased fluorescence intensity
- The shape of the spectrum is different for DH and UV ageing
- Complex behaviour of the spectra after combined ageing procedures esp. outdoors
- Spectral effects of UV and DH ageing can be separated also in case of outdoor weathered modules

- Fluorecence can be used for crack inspection (e.g. age of cracks)
- It can be used for determination of cross-linking efficiency in EVA during the lamination process
- It can be used for PV module inspection: in- and out-door
- Using minimized multi ageing chamber developed at HU Berlin different ageing parameters can be applied to one mini-module and differences in degradation behaviour can be analysed



THANK YOU FOR ATTENTION

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