A Guideline for Realistic Accelerated Aging Testing of Silvered-glass Reflectors

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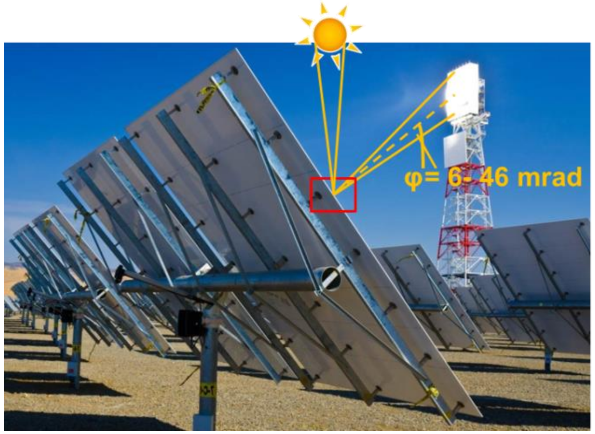
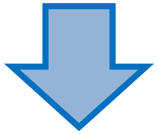
Solar Mirror Aging



- Primary mirrors first component in energy conversion process
  - Direct influence on output
  - No large scale replacement foreseen
- Exposure to harsh environmental conditions: desert (UV, erosion), coastal (corrosion)
- Crucial to maintain good optical properties
  - High specular reflectance
  - Expected lifetime: 25 years +



Evaluate durability by accelerated aging

Accelerated Aging Testing/Standardization

- Useful tool for durability evaluation
  - Fast results
  - Different purposes
    - Quality control
    - Material comparison
    - Lifetime prediction
  - Selection of realistic test procedures/parameters
- Standardization
  - Comparability of results
  - Assure meaningful, consistent results
- Up to today lack of agreement on which test are meaningful, parameters
- Few standards exist
  - Spanish UNE206016 (2018)
  - Guideline from Raiselife project (2020)

Input for international IEC proposal

Salt Spray testing according to ISO 9227

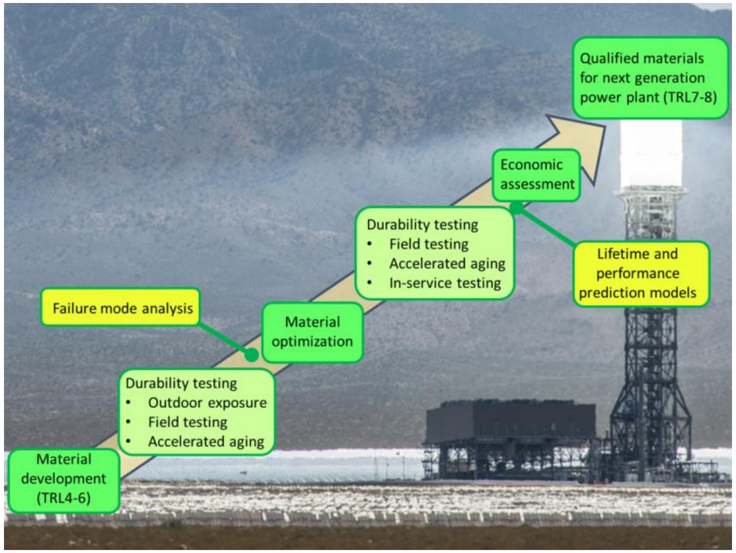
Sand erosion test bench at CIEMAT-PSA

Guideline Development

- EU Horizon 2020 project **Raiselife**
  - Goal to raise lifetime of CSP components (Receivers, Mirrors, etc.)
  - Work package on primary mirrors
- Guideline development
  - Public deliverable:

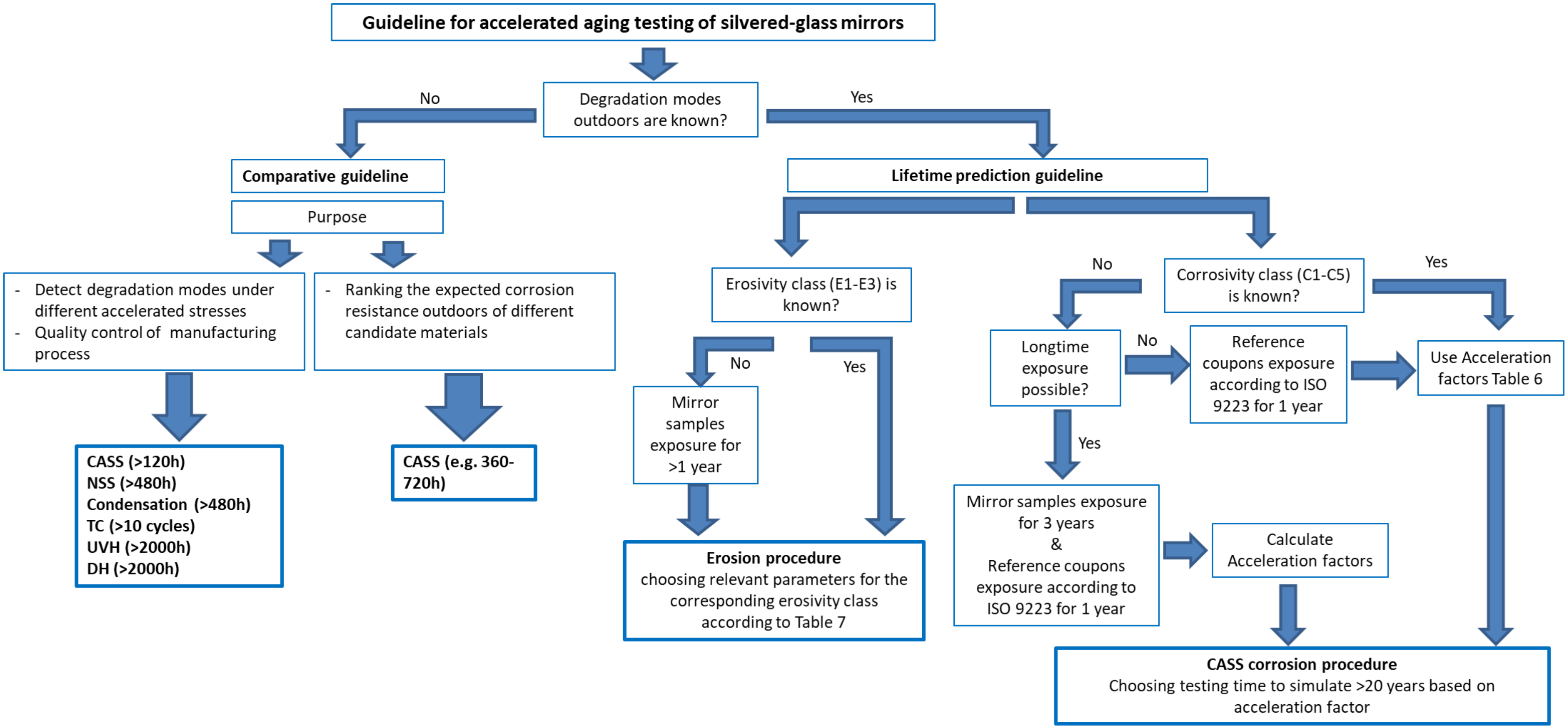
  „Guideline for accelerated aging testing of silvered-glass mirrors” [http://raiselife.eu]

- Based on results from large outdoor exposure and accelerated aging test campaign (20 materials, 11 outdoor sites, large number of laboratory tests and combinations)



RAISELIFE
The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 686008, project RAISELIFE.

Guideline Overview



Comparative procedure

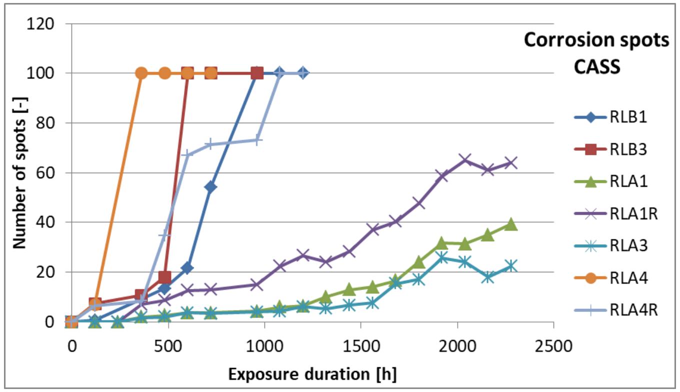
- Direct comparison between different reflector materials

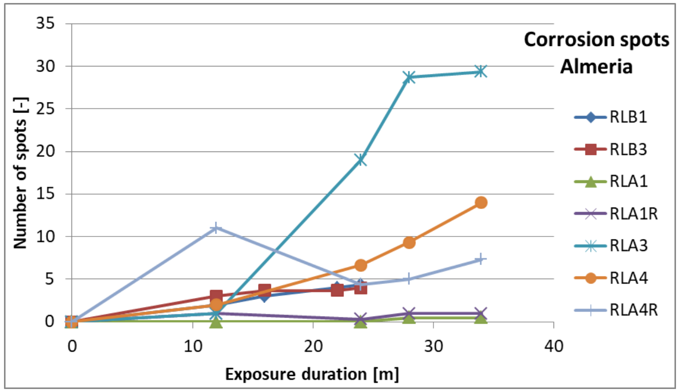
Test	Duration	Summary of testing conditions	Acceptance criterion
Neutral Salt Spray (NSS) ISO 9227	480/1000 h	T=35±2° C, pH=[6.5, 7.2] at T=25±2° C Sprayed NaCl solution of 50 ± 5 g/l Condensation rate of 1.5 ± 0.5 ml/h on a surface of 80 cm²	$\Delta\rho_{s,h}$≤0.004 $\Delta\rho_{\lambda,\varphi}$≤0.004 d_{corr} ≤0.01 cm^{-2} l_{corr} ≤0.1 cm
Copper accelerated acetic acid salt spray (CASS) ISO 9227	120/360 h	T=50±2° C, pH=[3.1, 3.3] at T=25±2° C Sprayed NaCl solution of 50 ± 5 g/l and 0.26 ± 0.02 g/l of $CuCl_2$ Condensation rate of 1.5 ± 0.5 ml/h on a surface of 80 cm²	$\Delta\rho_{s,h}$≤0.002 $\Delta\rho_{\lambda,\varphi}$ ≤0.002 d_{corr} ≤0.01 cm^{-2} l_{corr} ≤0.1 cm
Condensation ISO 6270-2 CH	480/2000 h	T=40±3° C RH=100%, with condensation on the samples	$\Delta\rho_{s,h}$≤0.002 $\Delta\rho_{\lambda,\varphi}$≤0.002 d_{corr} ≤0.01 cm^{-2} l_{corr} ≤0.1 cm
Combined thermal cycling and humidity UNE206016	10/40 cycles	4 h at T=85±2° C, 4 h at T=-40±2° C, Method A: 16 h at T=40±2° C and RH=97±3% Method B1: 16 h at T=85±2° C and RH=85±3% Method B2: 40 h at T=65±2° C and RH=85±3%	$\Delta\rho_{s,h}$≤0.002 $\Delta\rho_{\lambda,\varphi}$≤0.002 d_{corr} ≤0.01 cm^{-2} l_{corr} ≤0.1 cm
UV and humidity ISO 16474-3	1000 h (front side) + 1000 h (back side)	1 cycle: 4h at UV exposure at T=60±3° C followed by 4h at RH=100% at T=50±3° C	$\Delta\rho_{s,h}$≤0.004 $\Delta\rho_{\lambda,\varphi}$≤0.004 d_{corr} ≤0.01 cm^{-2} l_{corr} ≤0.1 cm
Taber Abrasion UNE206016	1000 cycles	Abradant of diameter ¾", mild abrading action, pushed force of 3.4 N on the mirror (0.012 N/mm²), 25 cycles per minute, stroke length of 8 ± 2 cm. Intermediate inspections after 200, 400, 600, 800 cycles.	$\Delta\rho_{\lambda,\varphi}$≤0.017
Damp Heat IEC 62108	2000 h	65° C and 85% RH	$\Delta\rho_{s,h}$≤0.01 $\Delta\rho_{\lambda,\varphi}$≤0.01 d_{corr} ≤0.2 cm^{-2} l_{corr} ≤0.1 cm

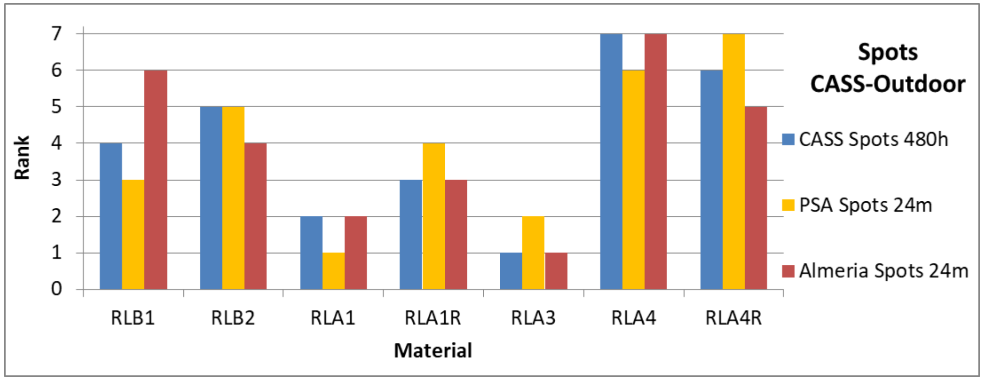
- Recommendation to complete whole UNE program + Damp Heat
- Especially if degradation modes are unknown
- Longer test durations than UNE minimum recommended to screen for additional degradation

Comparative Procedure – Resistance to Corrosion

- Based on CASS test
  - Testing time usually between 360-720h depending on appearing degradation
  - Ranking of the materials according to affected area by corrosion
- Comparison of **CASS** results with **outdoor** data showed very **good correlation** (2-3 years outdoor exposure on C3/C4 sites)
- Degradation after 3 years outdoor is still low even for aggressive sites







- **Verification of results with longer outdoor duration**
  - Stronger degradation
  - Also for less aggressive sites

Lifetime Prediction Procedure/Environment acceptance test

- End user of this standard needs to **define admissible reflectance loss** $\Delta\rho_{ad}$
- Erosion and corrosion are the main degradation modes. Other modes (e.g. silver-tarnishing or surface incrustations) are not considered in this standard

Reflectance loss due to degradation:

$$\Delta\rho_{ad} = \Delta\rho_e + \Delta\rho_c + \Delta\rho_o$$

$\Delta\rho_o$ → Not considered

$\Delta\rho_e$ → Test C.1: **Erosion**

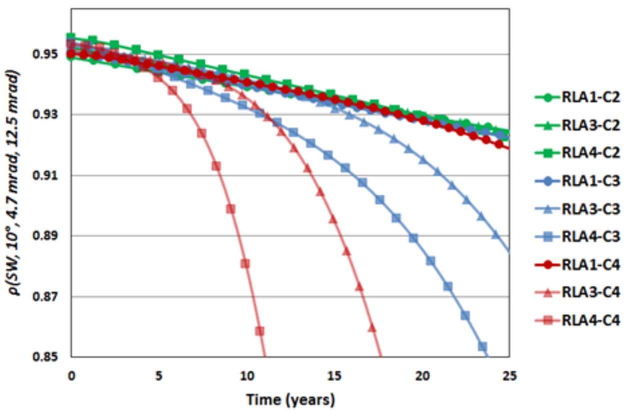
$\Delta\rho_c$ → Test C.2: **Corrosion**

Corrosion Prediction Procedure

- Scope: **Reproducing the corroded area A_c** (&reflectance), excluding edge corrosion, of mirror samples exposed outdoors

- Method:
  - Up to **2000h** of **CASS** test
  - **Quick method**: depending on site corrosivity class (C2-C4, ISO9223), admissible degradation in CASS is given (see parameters table)
  - **Improved method**:
    - Exposure of material samples on site (3 years)
    - Determination of acceleration factors to CASS
    - Calculation of expected degradation over time

Predicted reflectance drop for site classes



		Corrosivity class (according to ISO 9223) in which reflector shall be employed		
CASE	**t [h]**	**C2**	**C3**	**C4**
Guidance $\Delta\rho_c$=1% t_t= 20 yrs	480 (4 cycles)	0.014		
	720 (6 cycles)	0.071	0.005	
	1080 (9 cycles)	0.310	0.023	0.001
Custom $\Delta\rho_c$ and t_t	t	$< 1 - exp\left[\ln(1-\Delta\rho_c)\cdot\left(\frac{400\cdot t}{t_t}\right)^4\right]$	$< 1 - exp\left[\ln(1-\Delta\rho_c)\cdot\left(\frac{200\cdot t}{t_t}\right)^4\right]$	$< 1 - exp\left[\ln(1-\Delta\rho_c)\cdot\left(\frac{100\cdot t}{t_t}\right)^4\right]$

Erosion Prediction Procedure

- Scope: reproducing the erosion defects in size and density of reflector samples exposed at a height of 1.5 m above ground not surrounded by a wind fence, collectors or any other barriers, in two types of desert environments, named as E1 and E2.

- Method: Erosion is tested with sand blasting devices or wind tunnels with particle flow.
  v= 20m/s, α=45°

	Environment in which reflector shall be employed	
CASE	E1	E2
Guidance t_t= 20 yrs	m_d= 0.12 g/cm² m_s= 0 g/cm² $\Delta\rho_{\lambda,\varphi} < 0.025$	m_d= 0.32 g/cm² m_s= 1.46 g/cm² $\Delta\rho_{\lambda,\varphi} < 0.125$
Custom	$m_d = 0.006\ \frac{g}{cm^2 \cdot yrs} \cdot t_t$ m_s= 0 g/cm² $\Delta\rho_{\lambda,\varphi} < \Delta\rho_e$	$m_d = 0.016\ \frac{g}{cm^2 \cdot yrs} \cdot t_t$ $m_s = 0.073\ \frac{g}{cm^2 \cdot yrs} \cdot t_t$ $\Delta\rho_{\lambda,\varphi} < \Delta\rho_e$

AceTube setup at Ciemat-PSA

m_d Impacting mass density of MIL-STD-810 blowing dust particles (97-99% quartz, diameter 1-150µm)

m_s Impacting mass density of MIL-STD-810 blowing sand particles (>95% quartz, diameter 149-850µm)

E2 sites fulfill at least 2 of the following criteria: (a) the soil exhibits a significant proportion of fine sand (0.063-0.2 mm), (b) the average relative humidity over a meteorological year lies below 30%, (c) events with wind velocities stronger than 10m/s are taking place at least 300 hours per year.

E1 sites are less erosive and only one of the above listed criteria applies.

Thank you for you attention!
Questions?

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