# Moving from Weathering Screening Testing to Service Life Prediction

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**Abstract:**
Accelerated weathering test procedures of relatively short duration can at best only weed out very poorly performing materials intended for long duration applications such as solar energy. Materials that "pass" such screening tests could still undergo failure well before the expected service life of the system, thereby presenting significant performance and business risks. In contrast to the material agnostic, one-size-fits-all approach to screening tests, further risk reduction requires detailed understanding of the degradation and failure modes for the particular material system under consideration and careful experimental design. A general approach and two examples are described. The lifetime of coatings and laminates can be predicted using the rate of UV absorber loss while the lifetime of co-extruded multilayer materials is determined by the rate of erosion and the thickness of the protective layer.

# The Testing Corundum

- **Screening tests**
  - Material agnostic
  - Standardized conditions

    *but… use the best available UV source → ASTM D7869 or G155 xenon arc Daylight Type I*
  - Relatively short duration
  - Very wide confidence interval in results

- **Further risk reduction requires some sort of Service Life Prediction (SLP)**
  - Especially true for long-duration applications
  - Can take 2+ years of accelerated exposure to apply 20 years worth of UV
  - Higher acceleration increases risk of poor predictions

➢ **Requires knowledge of degradation processes for a specific material → *Science project***

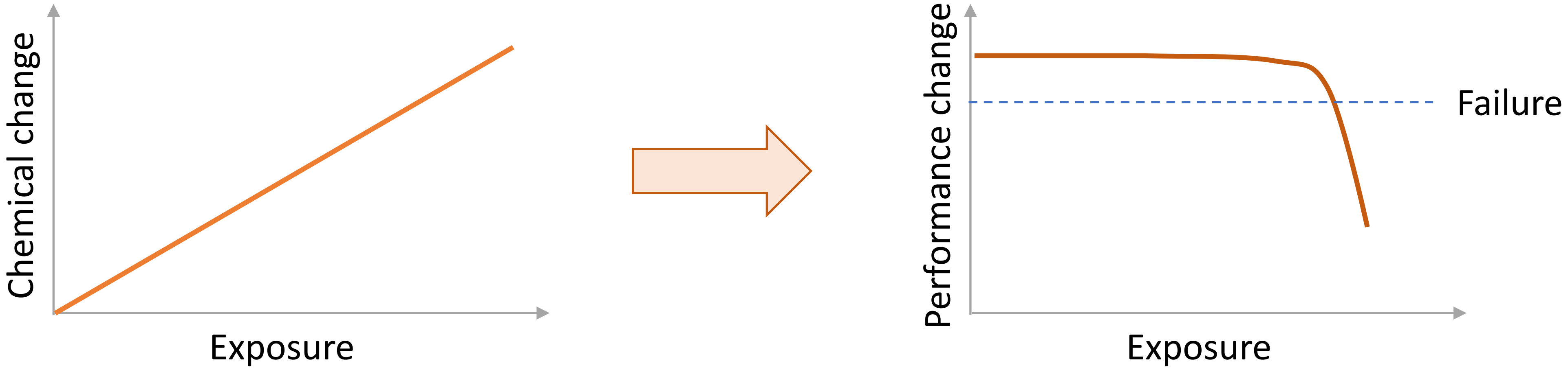
**References:**


1. Weathering of Plastics, in: **Handbook of Environmental Degradation of Materials** (3rd Edition), M. Kutz, Ed., Elsevier, 2018, pp. 163-184.
2. Introduction to Polymer Weathering, Stabilization, and Testing, in: **Service Life Prediction of Polymers and Coatings: Enhanced Methods**, C.C. White, et al. (Eds.), Elsevier, 2020, pp. 1-18.
3. Service Life Prediction: Why is this so hard?, In: **Service Life Prediction of Polymeric Materials: Over the Horizon,** C.C. White, et al. (Eds.), Elsevier, 2017, pp. 1-18.

# Lifetime Prediction Without Testing to Failure

- **Premises**
  - Chemical and physical changes throughout the exposure eventually lead to failure
  - Kinetics and rates of change can be determined
  - Amount of change necessary for failure can be determined

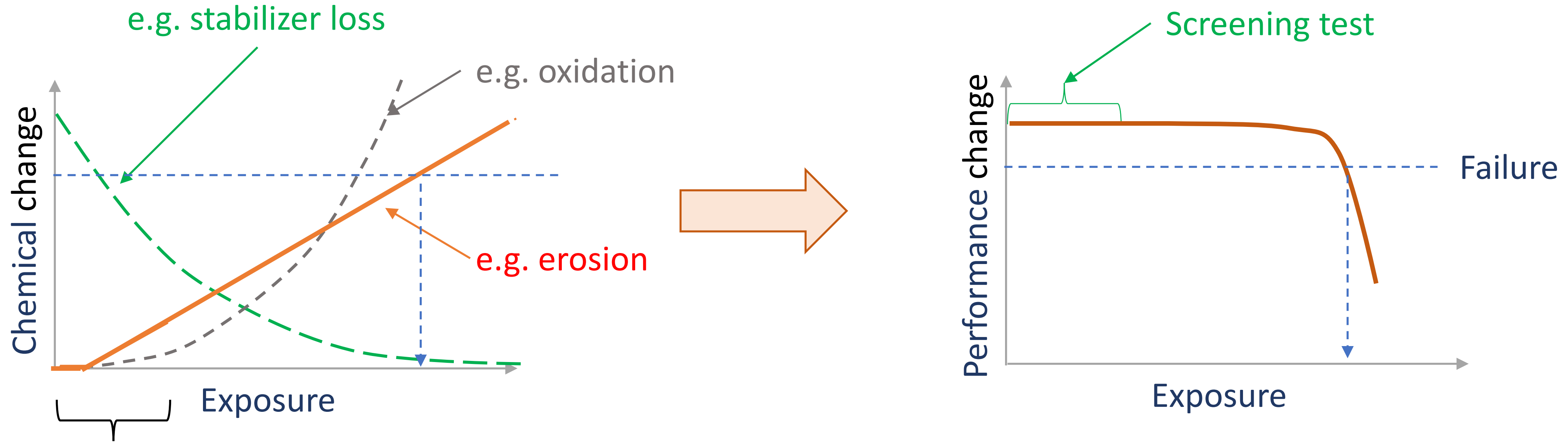
- **Examples**
  - Coatings/laminates
  - Co-extruded films
  - Stabilized polymers



# Chemical Kinetics and Performance Failure

- Short term pass/fail tests often cannot anticipate future failure
- Need to know what underlies failure
- Need to know how the change happens: kinetic law
- Need to know how much change leads to failure
- Then: can predict failure time from limited data without testing to failure

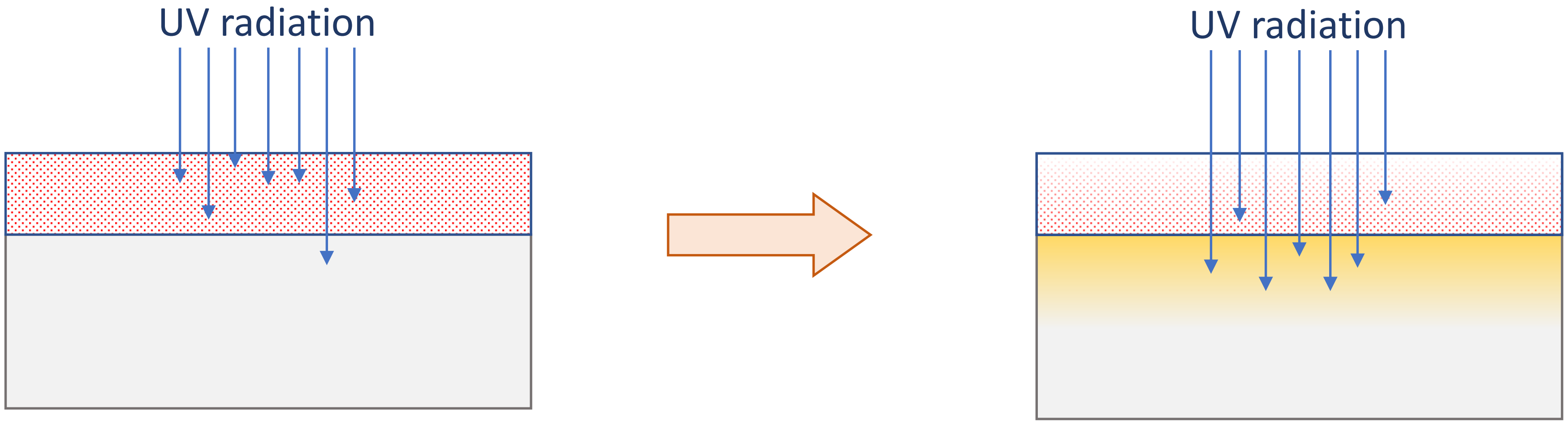
➢ *Need to know how exposure conditions relate to outdoors*




Determine rates
Extrapolate using kinetic law to failure point

# Example: Coatings and Laminates

- UV absorber in stable upper layer protects vulnerable functional layer
- UV absorber slowly degrades during exposure, letting UV penetrate
- Upon sufficient UV transmission, failure from delamination, yellowing, cracking, etc.




**References:**

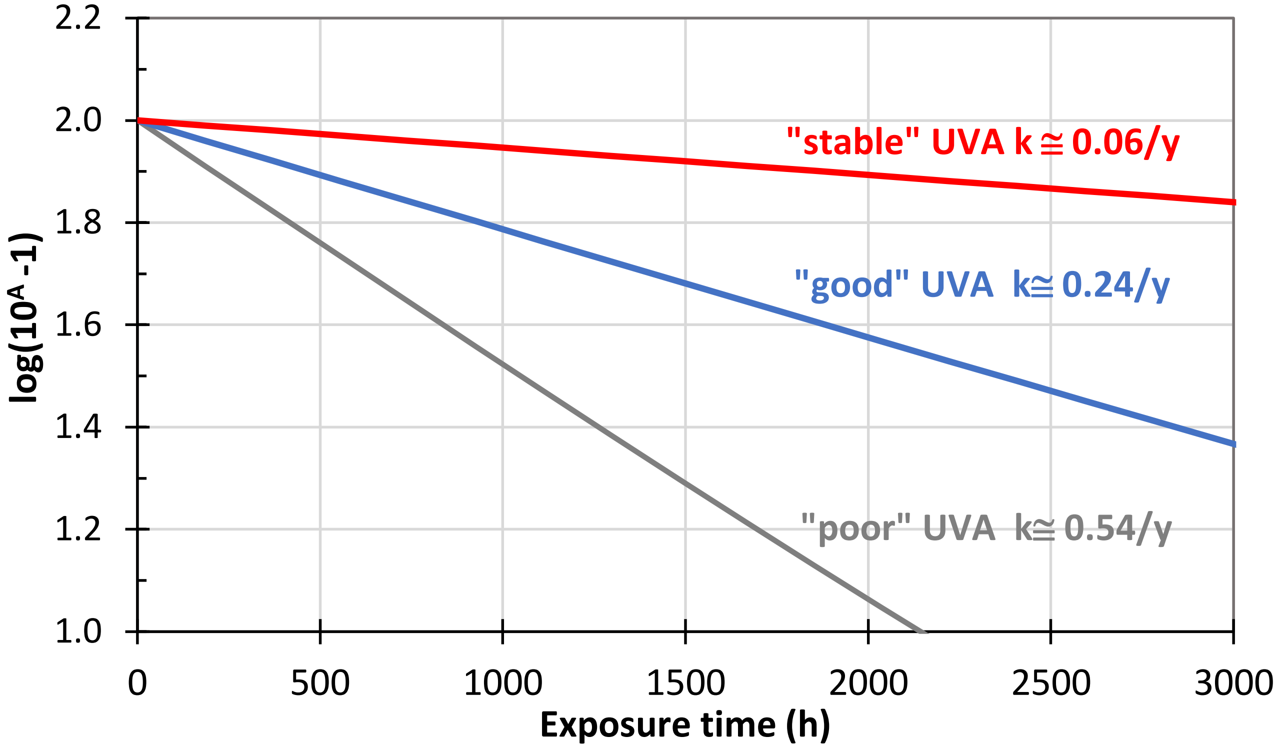
4. J.E. Pickett, UV Absorber Permanence and Coating Lifetimes, *Journal of Testing and Evaluation*, **32**, 240-245 (2004).
5. J.E. Pickett, Permanence of UV Absorbers in Coatings and Plastics, in: **Service Life Prediction, Methodology and Metrologies**, ACS Symposium Series 805, J. W. Martin and D. R. Bauer, Eds., 2002, pp. 250-265.
6. D.R. Bauer, Predicting In-Service Weatherability of Automotive Coatings: A New Approach, *J. Coatings Tech.*, **69**(864), 85-96 (1997).
7. R. Iyengar, B. Schellenberg, Loss rate of UV absorbers in automotive coatings, *Polym. Degrad. Stabil.*, **61**, 151-159 (1998).
8. J. David, An Analysis of Thermal and Humidity Cycling Stresses in Automotive Hard Coatings, in: **Service Life Prediction of Polymers and Coatings: Enhanced Methods**, C.C. White, et al. (Eds.), Elsevier, 2020, pp. 183-207.

# Example: Coatings and Laminates

Rate constant for absorbance loss

- **Kinetics of UV absorber loss**
  - known from extensive research: $A_t = \log_{10}[(1\text{-}T_o)\ 10^{(A_o - kt)} + 1]$ (Ref. 4, 7)
  - initial Absorbance and Transmission can be measured or calculated; $T_0 = 10^{-A_0}$
  - ***k*** easily determined experimentally using free-standing film or on stable, transmitting substrate

    *need to eliminate or correct for absorption changes in substrate!*
  - can be determined in a few thousand hours for more stable UV absorbers




Calculated for UVA in acrylic coating
Xenon arc Type I daylight filters, 0.75 W/m² at 340 nm
Assume ~ 3 MJ/m² xenon arc = 1 year Florida

$$\log(10^{A_t} - 1) = \underbrace{-\mathbf{k}}_{\text{slope}} t + \underbrace{A_o + \log(1-T_o)}_{\text{intercept}}$$

## Example: Coatings and Laminates

- **Predicting failure time**
  - known from research: $$t_{fail} = \frac{1}{k}\log_{10}\left[\frac{10^{kD_{fail}} + T_0 - 1}{T_0}\right]$$ (Ref. 4, 5)
  - $\boldsymbol{D_{fail}}$ (transmitted dose to failure) can be determined by testing system with no UV protection

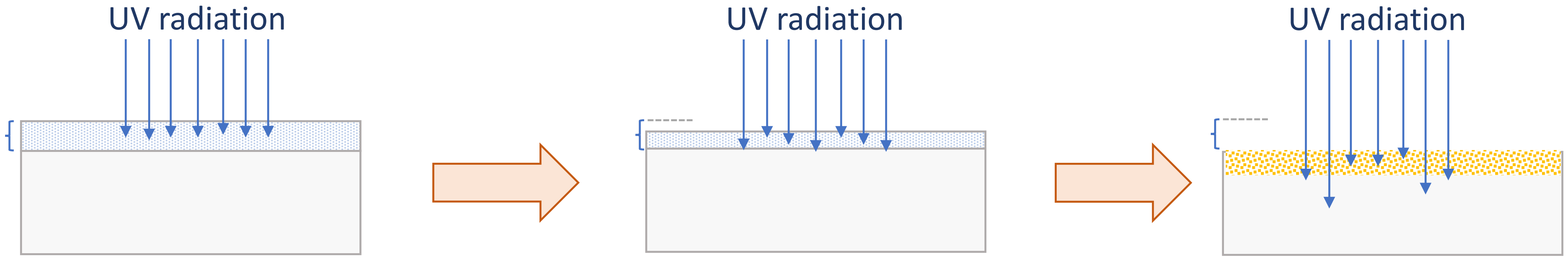
- **Can estimate fail times without testing to failure for various coating or laminate designs**

| | | | | | |
|---|---|---|---|---|---|
| Dose for Failure (years) | 1 | 1 | 1 | 1 | 1 |
| UVA loss rate ($year^{-1}$) | 0.54 | 0.24 | 0.24 | 0.06 | 0.06 |
| Initial absorbance | 2 | 2 | 5 | 2 | 2.5 |
| **Calculated fail time** (years) | **4.4** | **8** | **20** | **20** | **28** |

- **This is maximum lifetime—coatings can fail earlier by cracking, etc.** (Ref. 8)

# Example: Co-extruded film and sheet

- **Layer with very high loading of UV absorber co-extruded on substrate with low UV absorber**
  - UV penetration very shallow because of high UVA loading
  - Very small amount of initial degradation of cap layer
  - Cap layer undergoes slow, uniform erosion
  - Eventually, cap layer eroded away and substrate rapidly degrades
- **Lifetime function of erosion rate and cap layer thickness**




as made
cap layer fully protects substrate

cap layer eroded
still protecting substrate

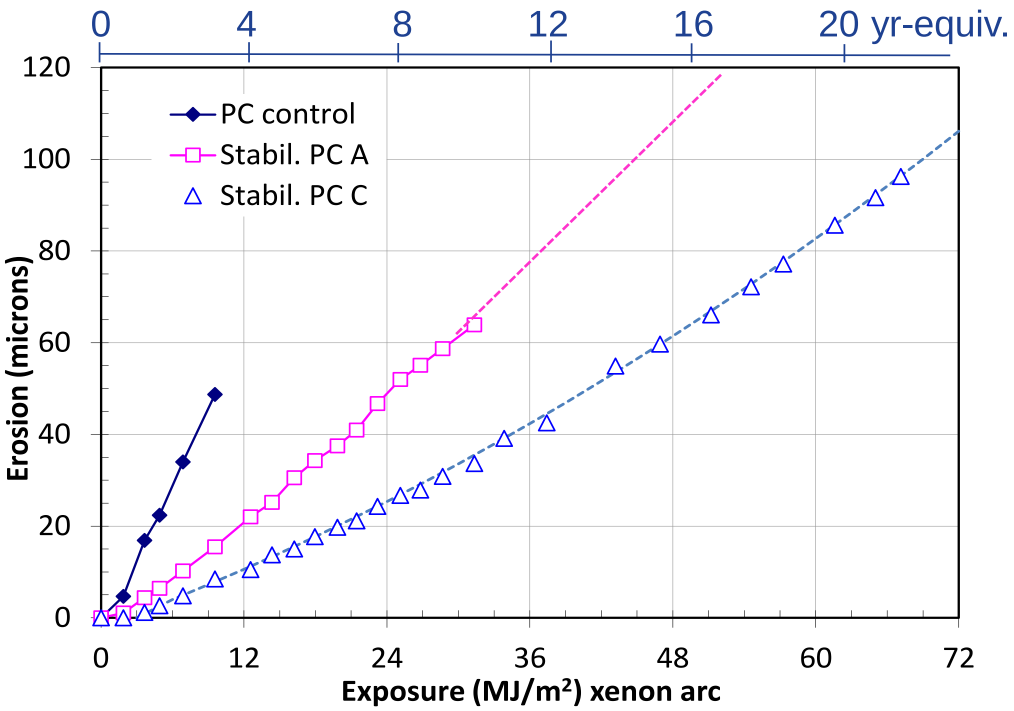
cap layer gone
substrate degraded

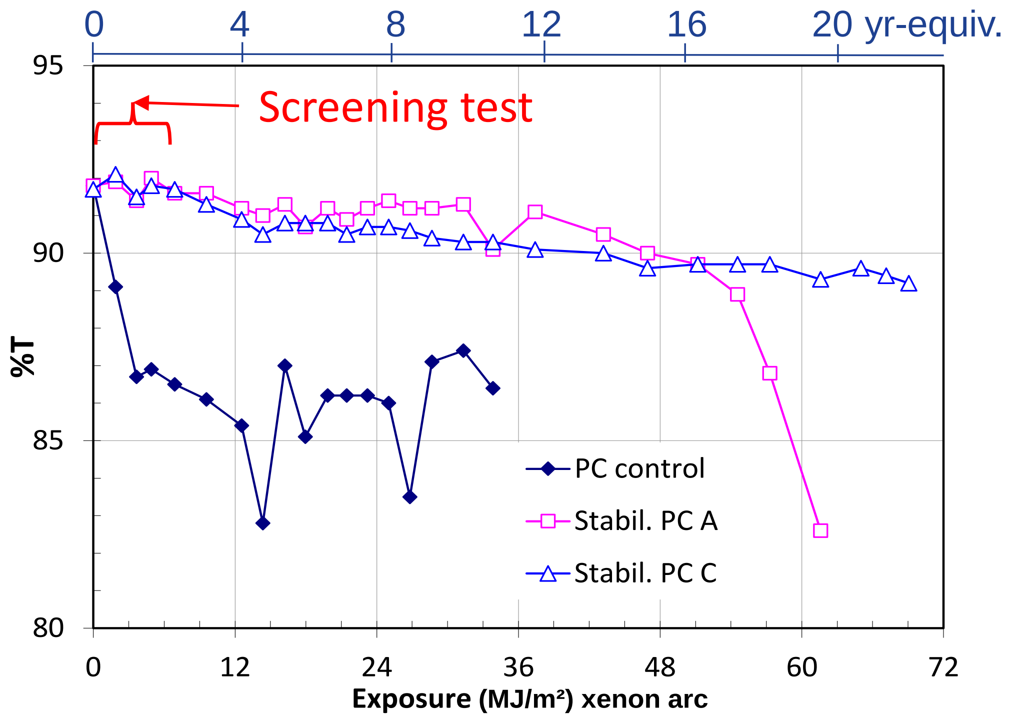
**References:**

9. O. Frank, Material wear and erosion at the surface of plastics caused by weathering, *Angew. Makromol. Chem.*, **176/177**, 43-53 (1990).
10. J. Pickett, et al., Polycarbonate Stability in Solar Energy Applications, Atlas/NIST PV Material Durability Workshop, Gaithersburg, Maryland, Oct. 27-28, 2011.
11. J. Pickett, et al., Polycarbonate Stability in Solar Energy Applications, Plastics in Photovoltaics 2012, AMI Conferences, Phoenix, Arizona, Sept. 19-20, 2012.

## Example: Co-extruded film and sheet

- **Prediction method**
  - Mount sample with removable opaque mask
  - Expose and periodically remove mask and measure step height with a profilometer
  - Extrapolate to get cap layer thickness needed for desired lifetime (these were ~ 120 microns thick)



# Other strategies

- Extrapolation from under-stabilized formulations  (Ref. 12, p. 277, 304)
- Extent of oxidation by IR spectroscopy (Ref. 13)
- Molecular weight loss (Ref. 14)

**References:**

12. F. Gugumus, Light Stabilizers, In: **Polymer Additives Handbook**, 6th Ed., H. Zweifel, et al. eds., Hanser Publishers, 2009, pp. 139-423.
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14. W. McMahon, H.A. Birdsall, G.R. Johnson, C.T. Camilli, Degradation studies of polyethylene terephthalate, *J. Chem. Eng. Data*, **4**, 57-97 (1959).

# Conclusions

- **Short-term accelerated weathering screening tests can identify only very early failures**

- **Further risk reduction requires knowledge of degradation modes and chemistry *for specific materials***

- **Predictions after a few thousand hours of exposure can be made if we know:**
    - kinetic law for the relevant degradation pathway
    - rate constants
    - amount of degradation required for failure

- **Carefully designed experiments can give necessary information fairly quickly**

- **This approach can be faster and more reliable than highly accelerated testing to failure**