Weathering Testing for Retroreflective Sheetings

a retro-perspective after 25 years of research

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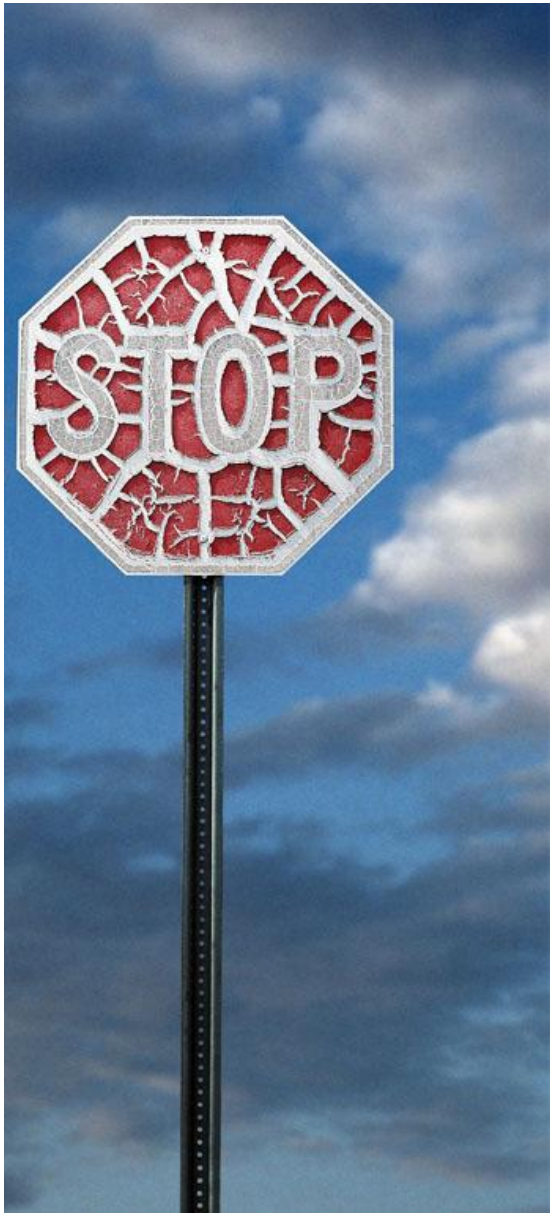
Weathering Tests for Retroreflective Sheetings

- In-use weathering
  - Warranty times from 1 to 15 years
- Outdoor Weathering
  - Product development
  - Warranty development
  - Specifications
- Artificial Accelerated Weathering
  - Specifications
  - Product development
  - Estimating service life

Retroreflective Sheeting Degradation

- Retroreflectance loss
  - Surface degradation
  - Optical instability
  - Vapor coat oxidation
- Color shift or fade
- Delamination and adhesion failures
- Dimensional changes
  - macro effects
  - micro effects

➔ **Weathering tests must simulate ALL critical failure modes**

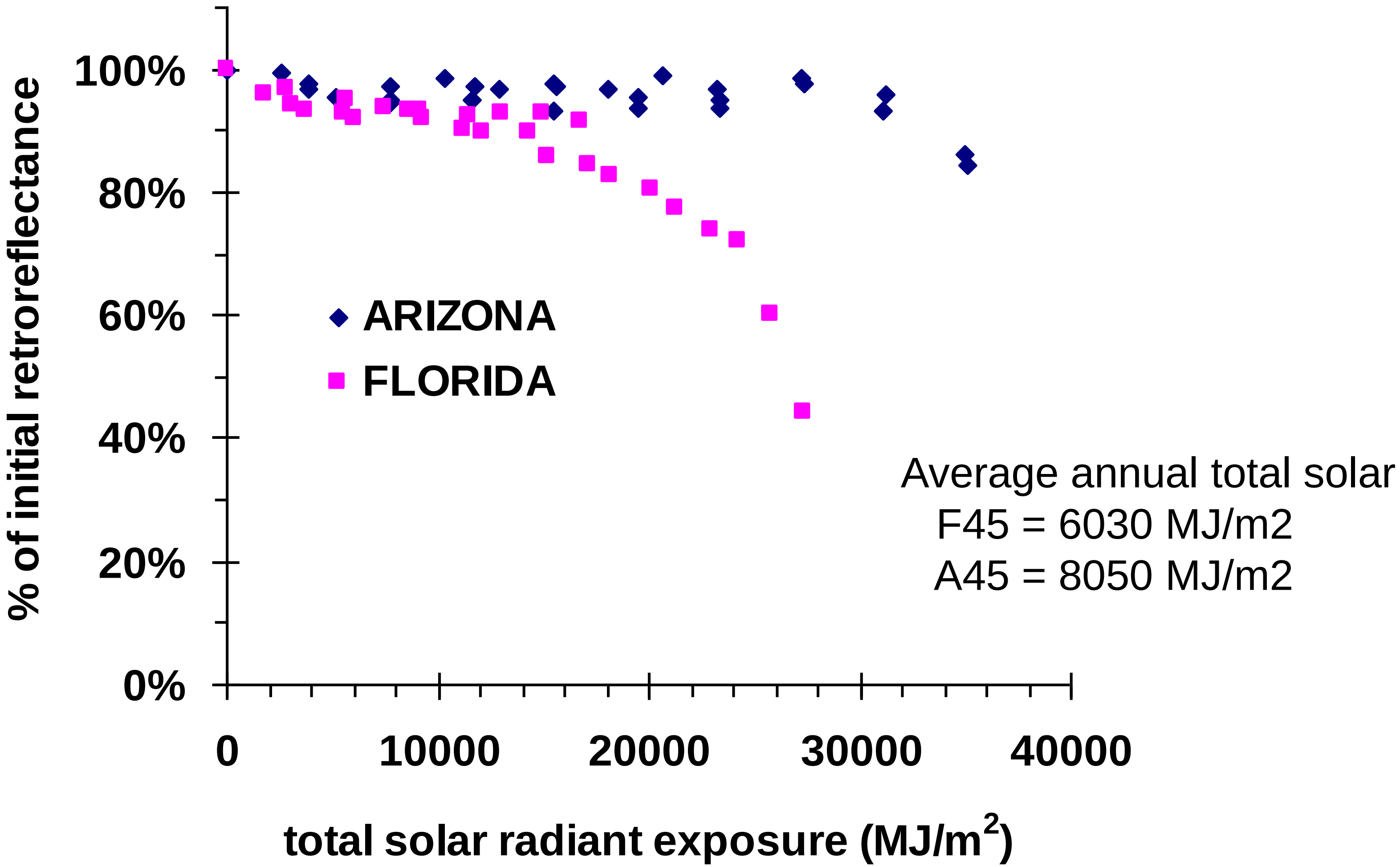


Outdoor Weathering

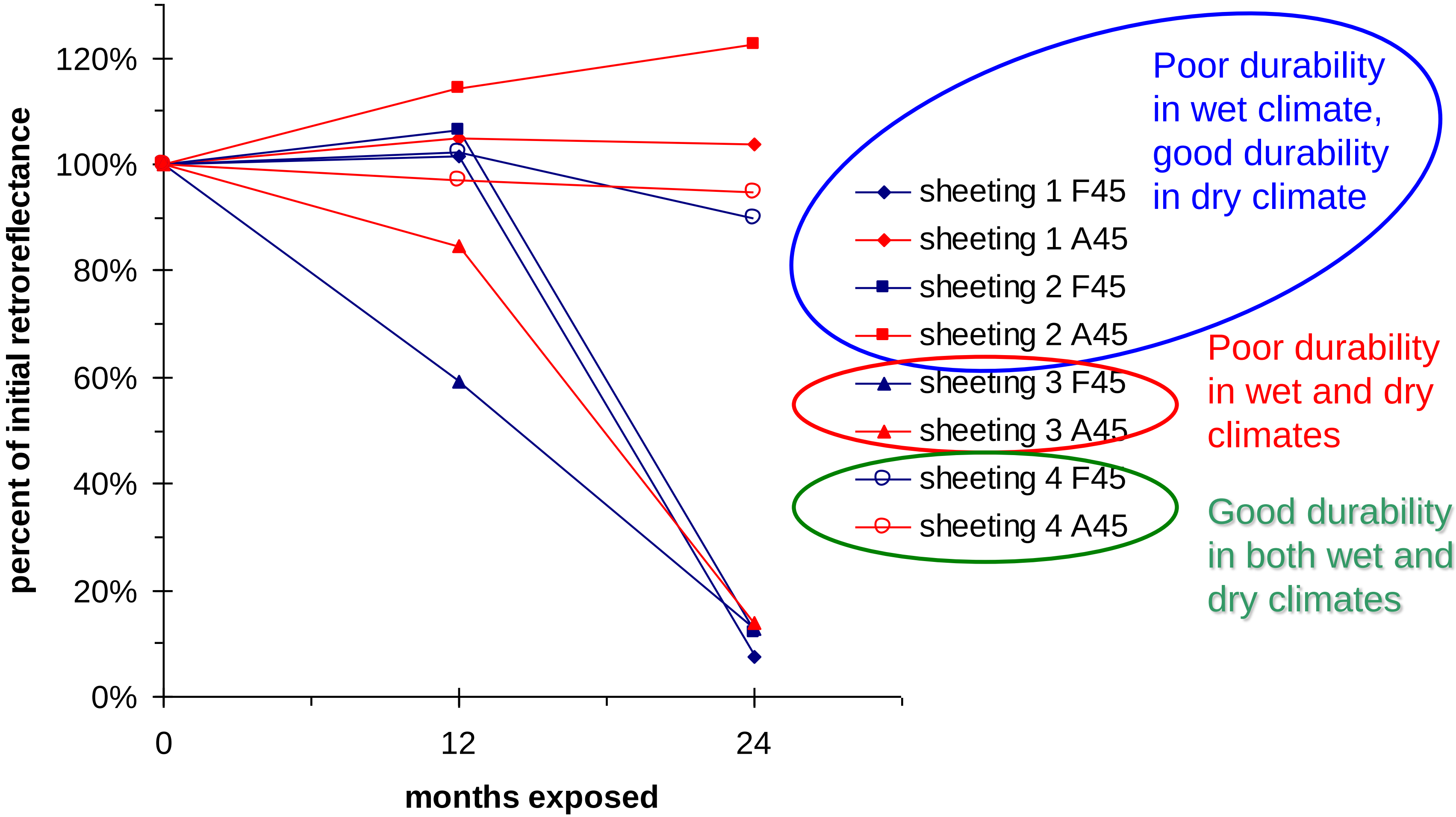
- **Variable**
  - Different climates
  - Variation at a single location
- **Slow**
  - 6 months to 6 years
  - Accelerated outdoor
    - 45º exposures assumed to provide 2:1 acceleration relative to vertical
- **Never wrong**

Climate Effects on Degradation Rate

effect of moisture on a yellow Type III sheeting

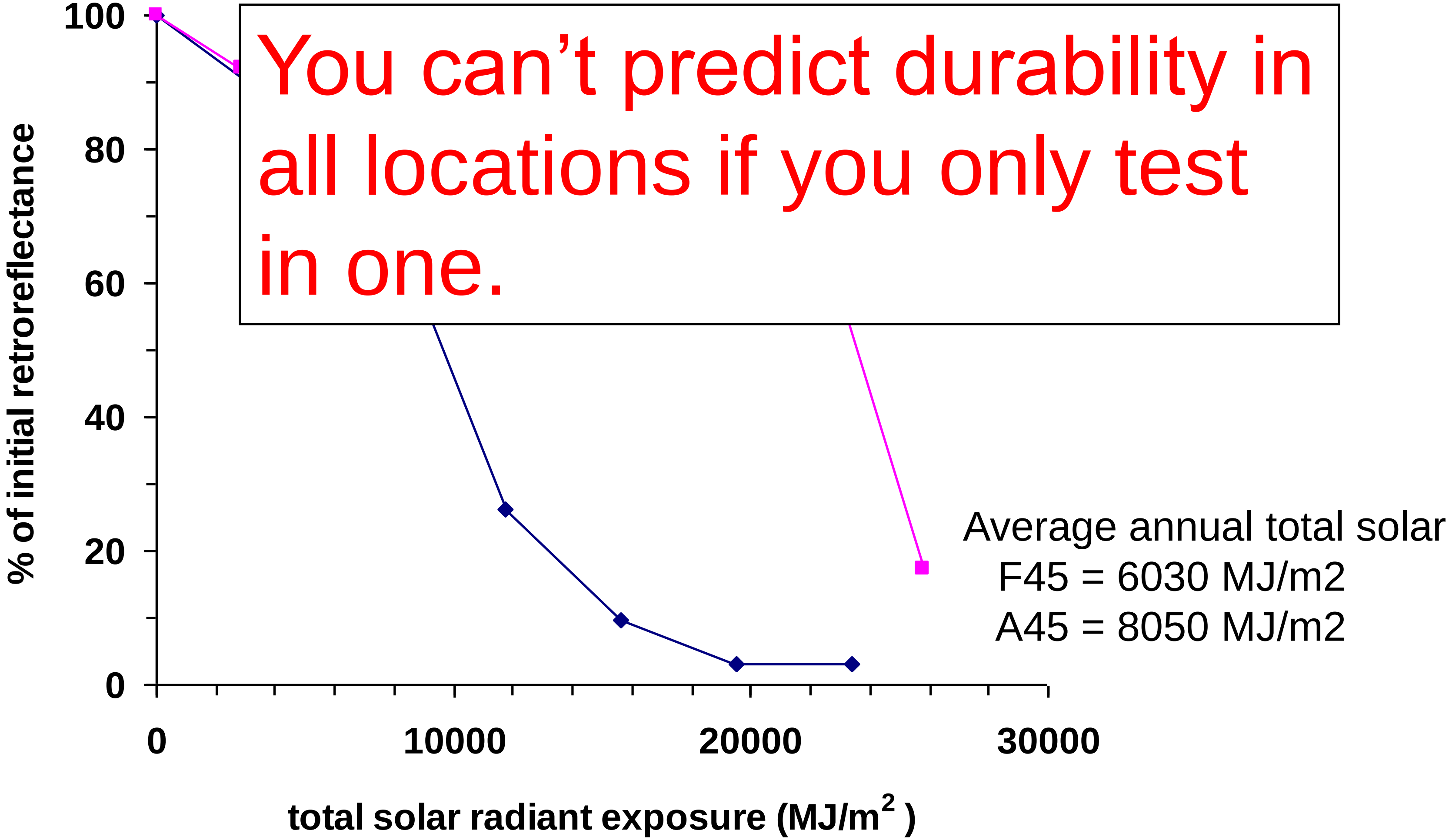


Effect of Moisture on Durability of Conspicuity Sheetings



Climate Effects on Degradation Rate

effect of Heat a Type I Sheeting

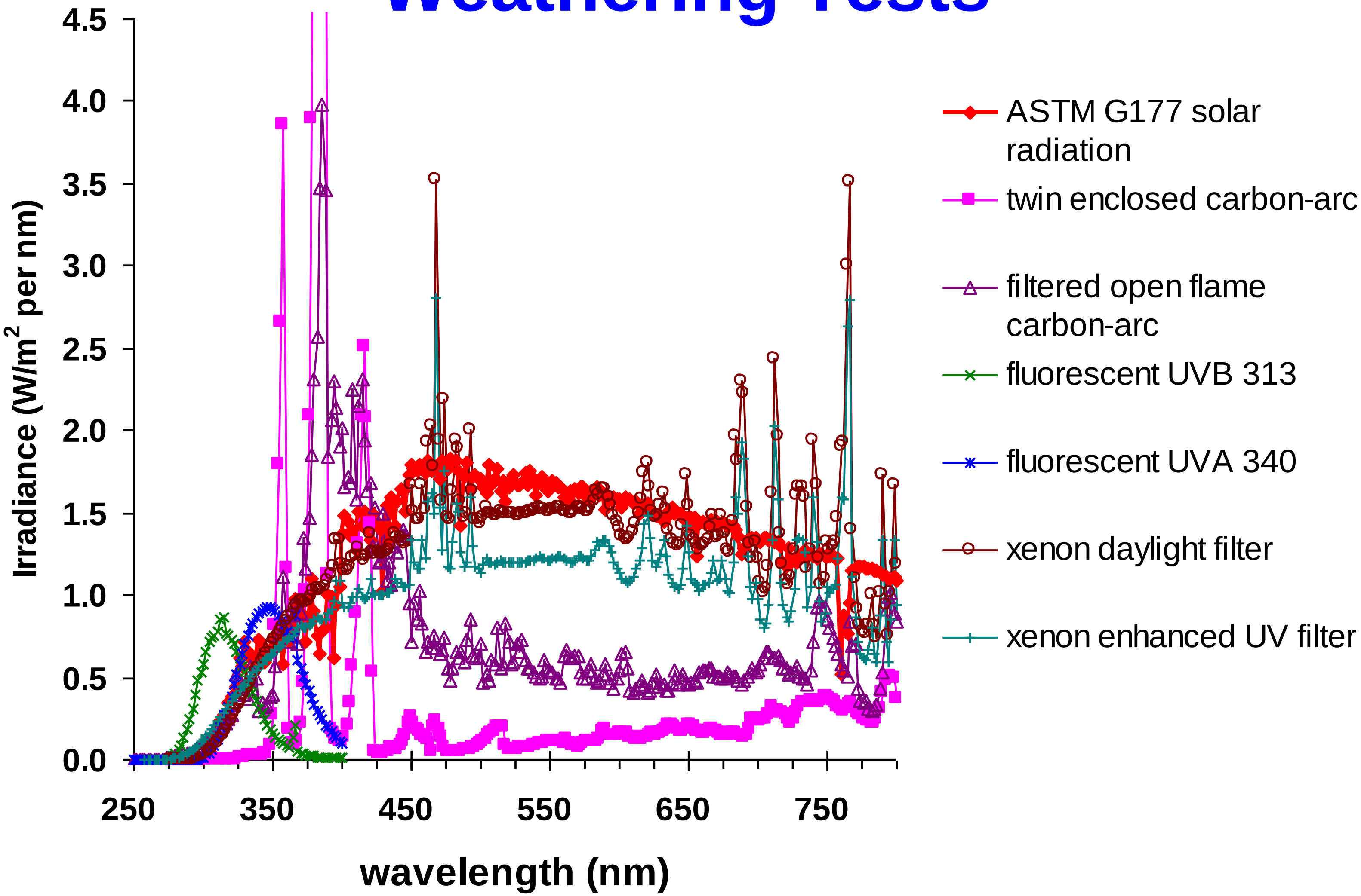


You can't predict durability in all locations if you only test in one.

Artificial Accelerated Weathering

- Fast
  - Typical 500 hr to 3500 hr in specifications
- Different light sources used
  - Carbon-arc
    - Enclosed or filtered open-flame
  - Fluorescent UV
    - UVB or UVA
  - Xenon-arc
    - Extended UV or daylight filters

Light Sources Used in Accelerated Weathering Tests



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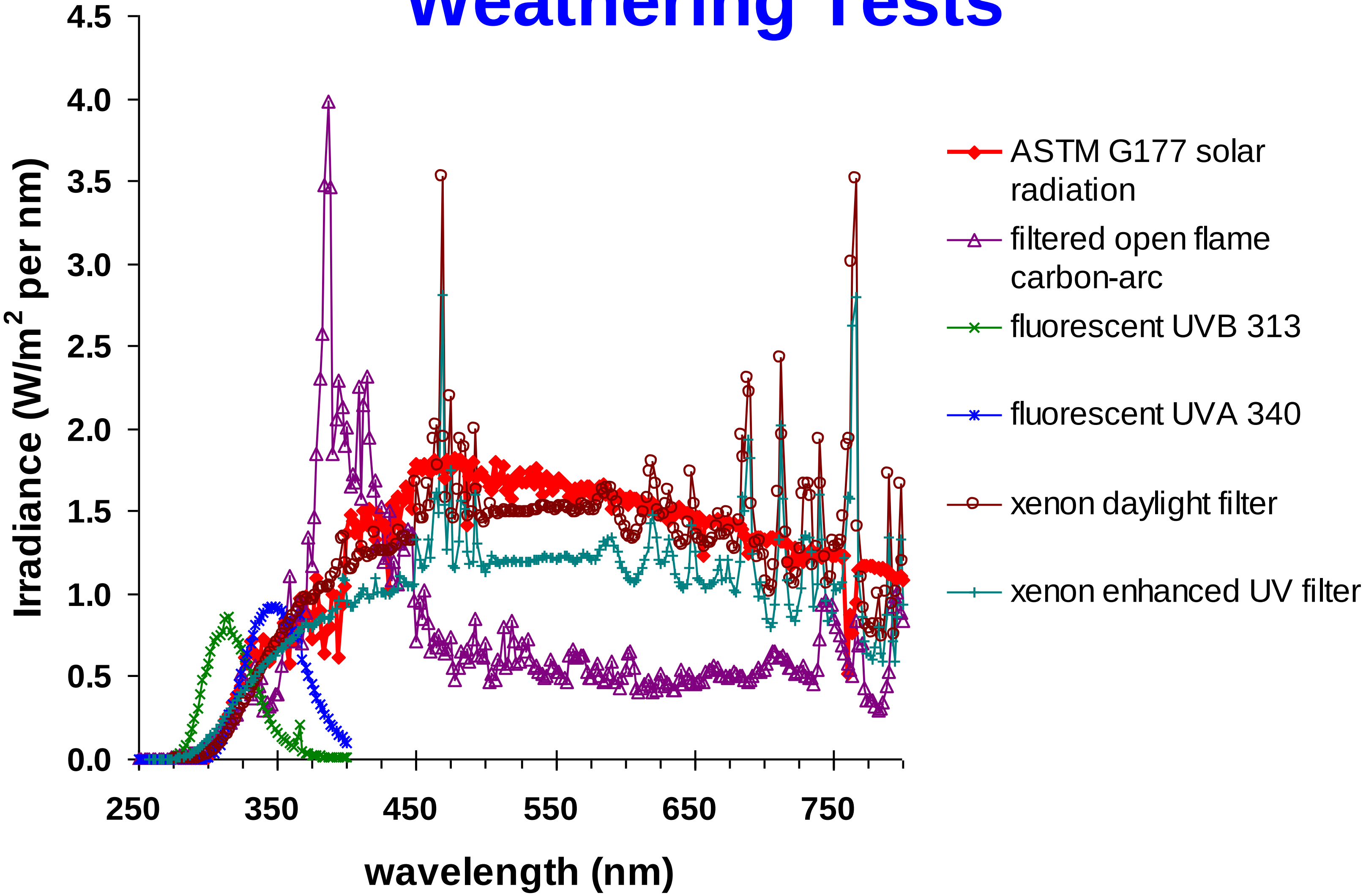

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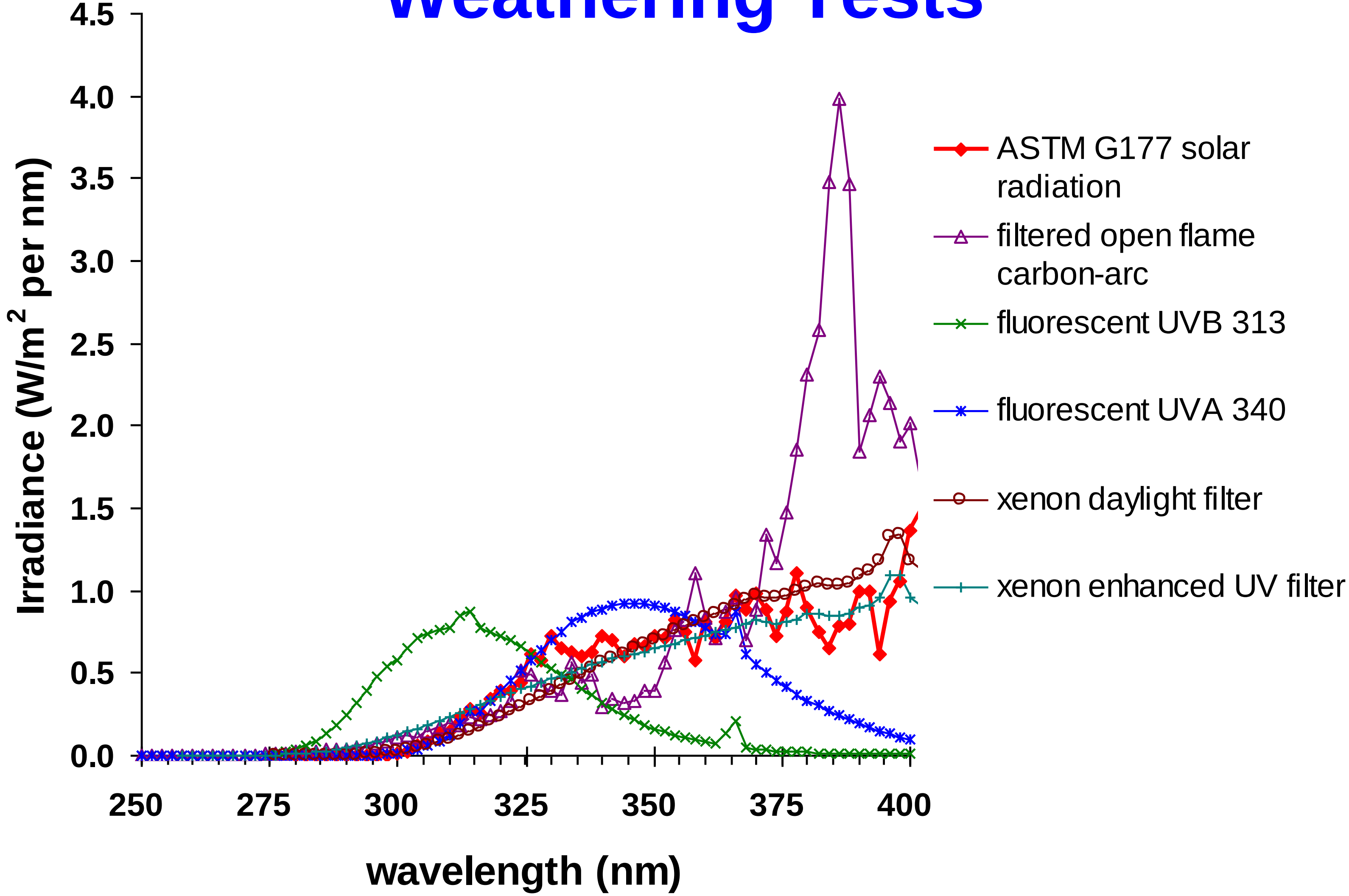

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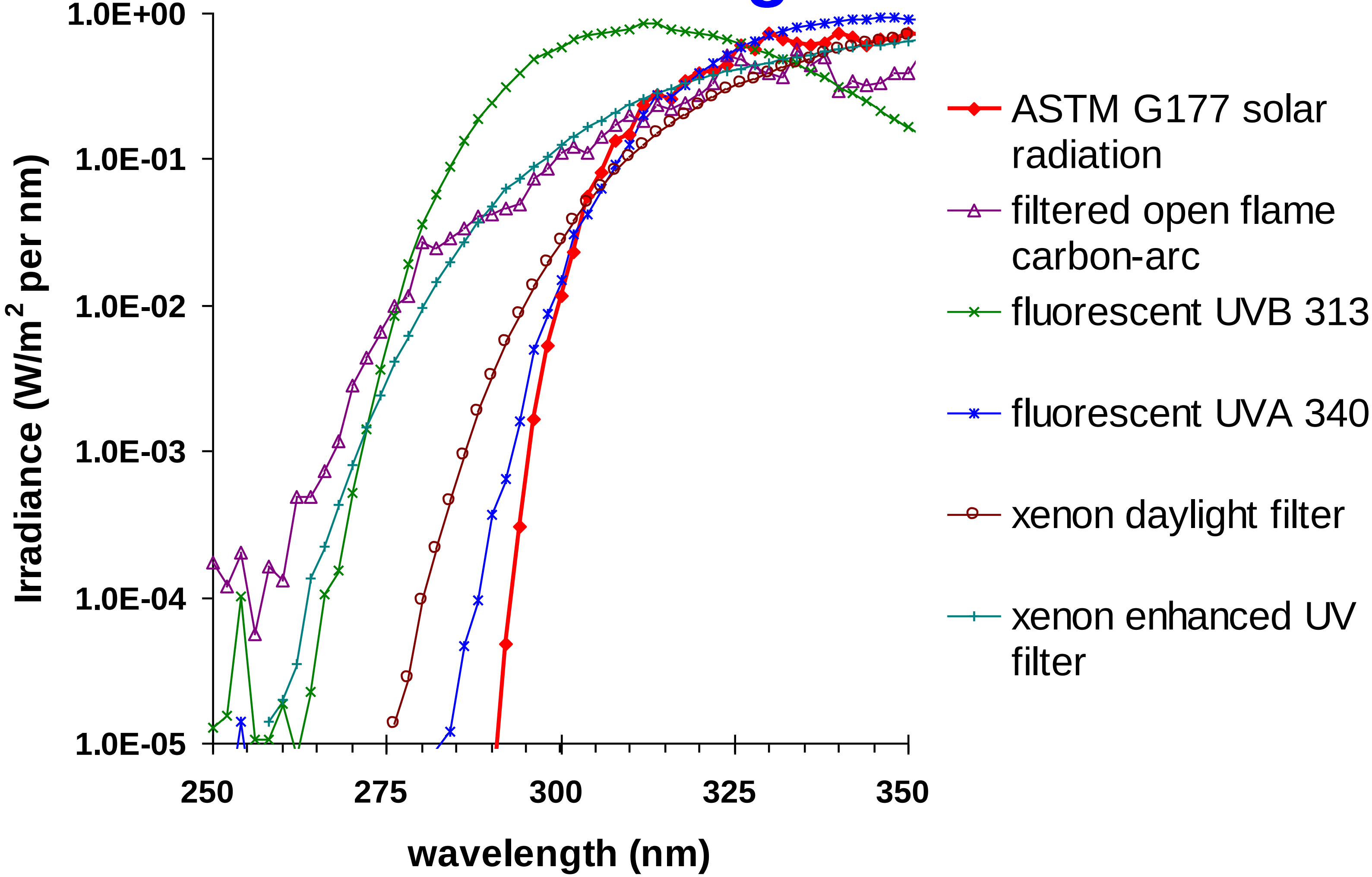


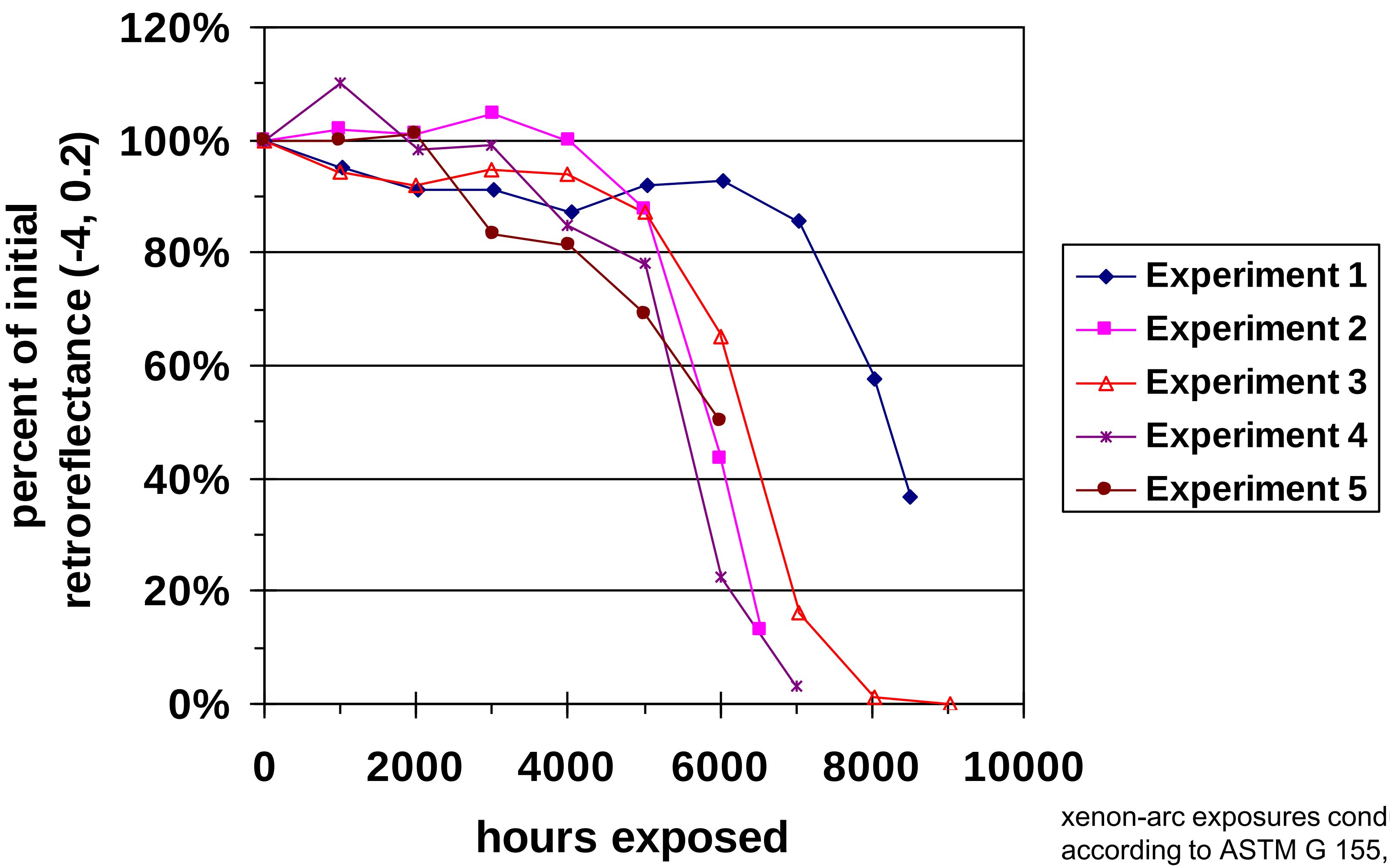
Common Assumptions About Using Laboratory Accelerated Tests

- **Laboratory accelerated tests are more consistent than outdoor exposures**
- **Materials that meet requirements of a test that uses aggressive conditions will be durable in actual outdoor use**

If the Assumptions About Laboratory Accelerated Tests Are Wrong…..

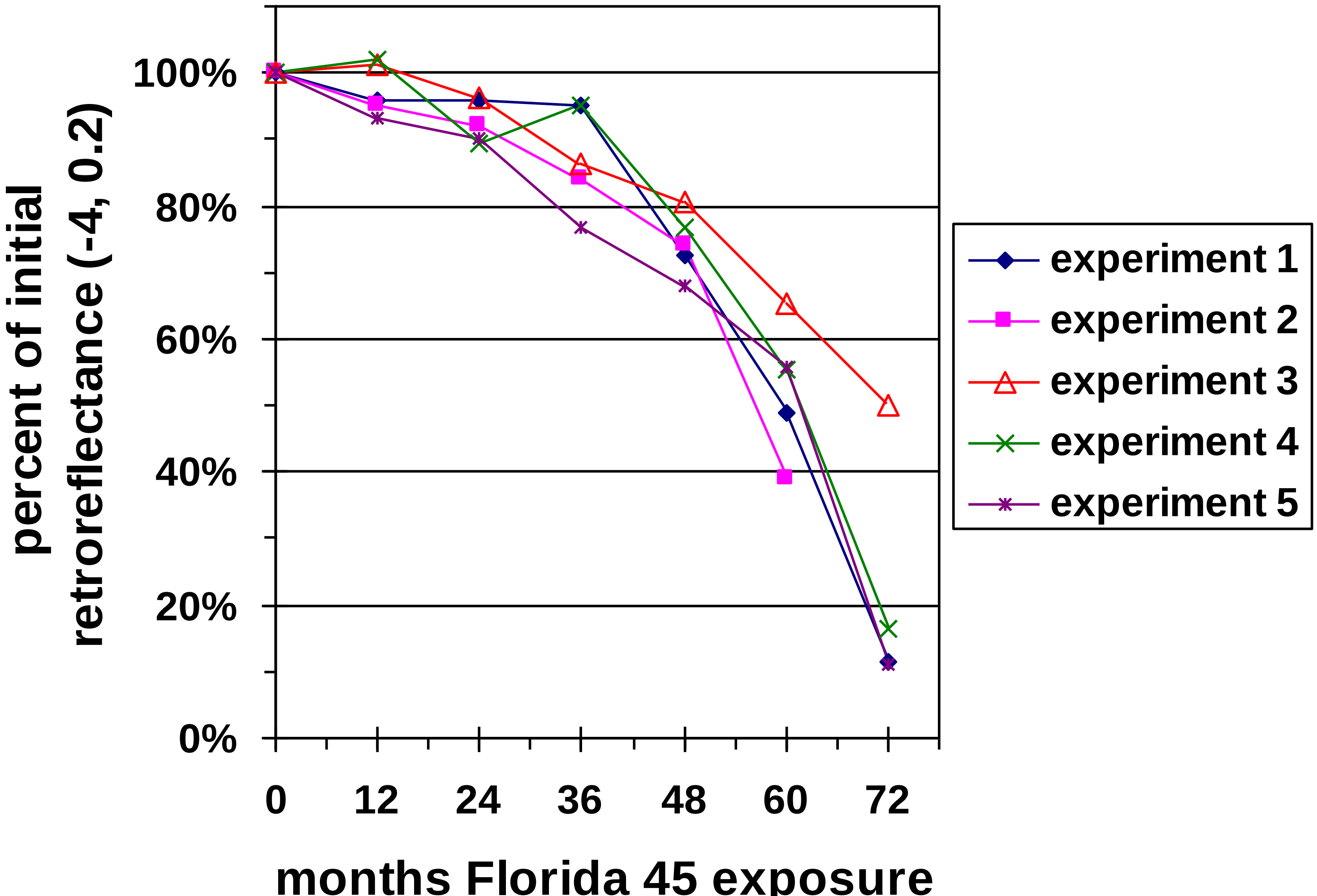
- Get inconsistent results

Repeat Xenon-Arc Exposures of a Single Lot of ASTM Type III Yellow Sheeting

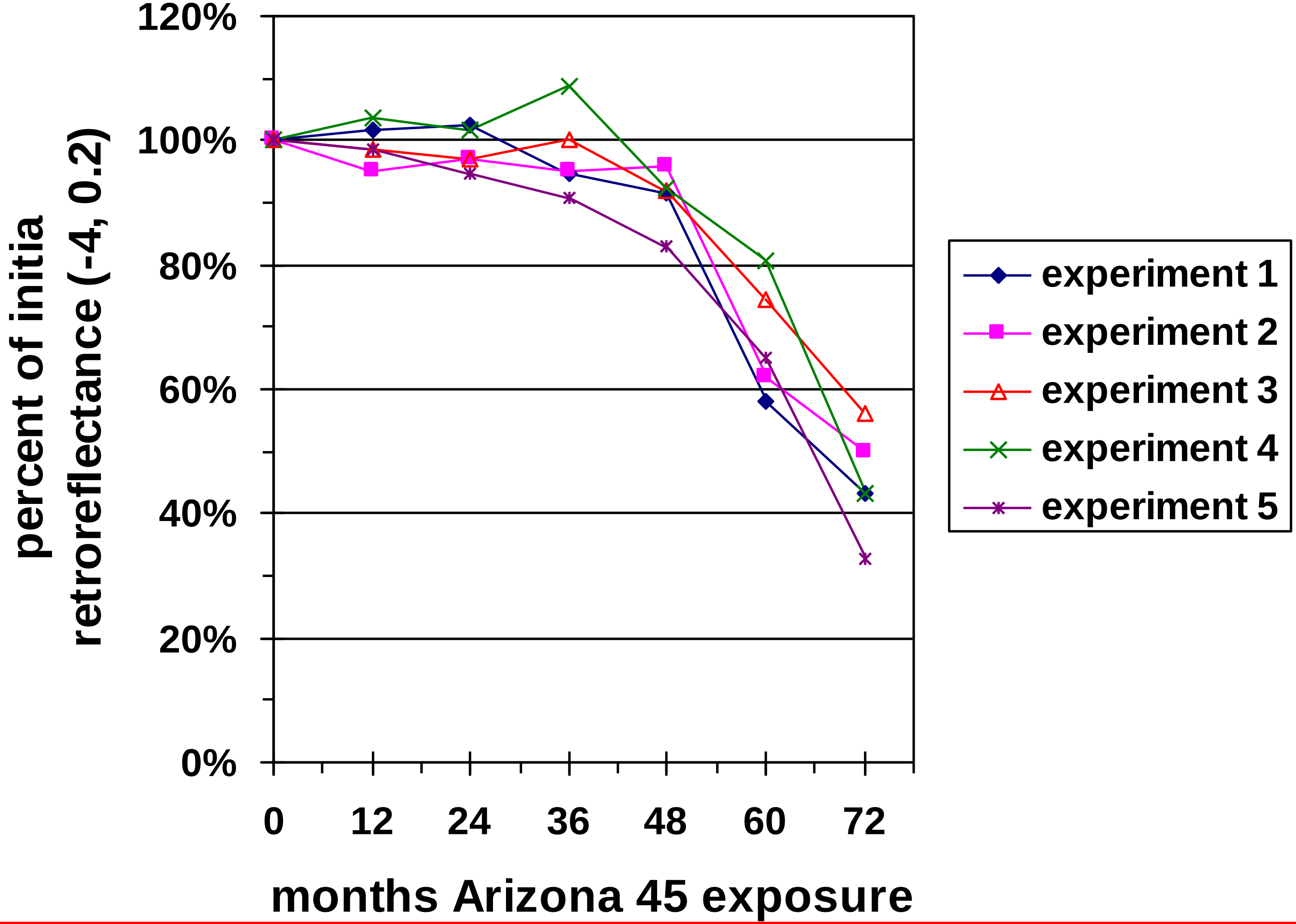


xenon-arc exposures conducted according to ASTM G 155, Cycle 1

Repeat Florida 45 Exposures of a Single Lot of ASTM Type III Yellow Sheeting



Repeat Arizona 45 Exposures of a Single Lot of ASTM Type III Yellow Sheeting



Comparison of Test Repeatability

Have never found a standard laboratory accelerated test to be more consistent than outdoor exposures

Time to 50% loss of initial retroreflectance for single lot of Type III yellow sheeting

Experiment Number	Hours Xenon-arc	Months Florida 45	Months Arizona 45
1	8210	60	66
2	5872	56	72
3	6330	72	76
4	5528	62	70
5	6013	62	66
Minimum	5528	56	66
Maximum	8210	72	72
% CV	17%	10%	6%

Impact of test variability on calculation of acceleration factors

Largest accel. factor	921 hr = 1 yr F45	921 hr = 1 yr AZ45
smallest accel. factor	1759 hr = 1 yr F45	1492 hr = 1 yr AZ45

xenon-arc exposures conducted according to ASTM G 155, Cycle 1

If the Assumptions About Laboratory Accelerated Tests Are Wrong…..

- Get inconsistent results
- Reject materials that have good outdoor durability
- Fail to distinguish between materials with "good" and "excellent"durability
- Accept materials that have poor outdoor durability
  - This is the most dangerous error

Laboratory accelerated tests may show poor correlation with outdoor exposures

Material	% of initial retroreflectance (-4°, 0.2°) 4000 hr Xenon-arc	4000 hr Fluorescent UVB	60 months F45	72 months AZ45
A	68	95	59	42
B	67	85	77	42
C	69	84	80	42
D	69	94	92	100
E	62	77	89	100
F	58	20	61	51
G	60	34	67	64

Xenon-arc exposure according to ASTM G 155 cycle 1
Fluorescent UVB exposure according to ASTM G 154 cycle 2

Laboratory accelerated tests may show poor correlation with outdoor exposures

Little differentiation between best and worst

Worst rated same as best

% of initial retroreflectance (-4º, 0.2º)

	4000 hr enon-arc	000 hr orescent UVB	60 months F45	72 months AZ45
A	68	95	59	42
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Xenon-arc exposure according to ASTM G 155 cycle 1
Fluorescent UVB exposure according to ASTM G 154 cycle 2

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Spearman rank correlation to 60 mo F45 or 72 mo A45				
60 mo F45	0.45	0.11	1.00	0.70
72 mo A45	0.14	0.13	0.70	1.00

Failure to Distinguish Between Sheetings with Obvious Durability Difference

	% RETAINED RETROREFLECTANCE	
EXPOSURE TEST	TYPE I SHEETING A	TYPE I SHEETING B
FLUORESCENT UVB		
initial	100%	100%
500 hr	96%	96%
1000 hr	97%	100%
1500 hr	78%	78%
FLORIDA 45		
initial	100%	100%
12 months	91%	97%
24 months	30%	91%
36 months	2%	85%

Fluorescent UVB exposure according to ASTM G 154 cycle 2

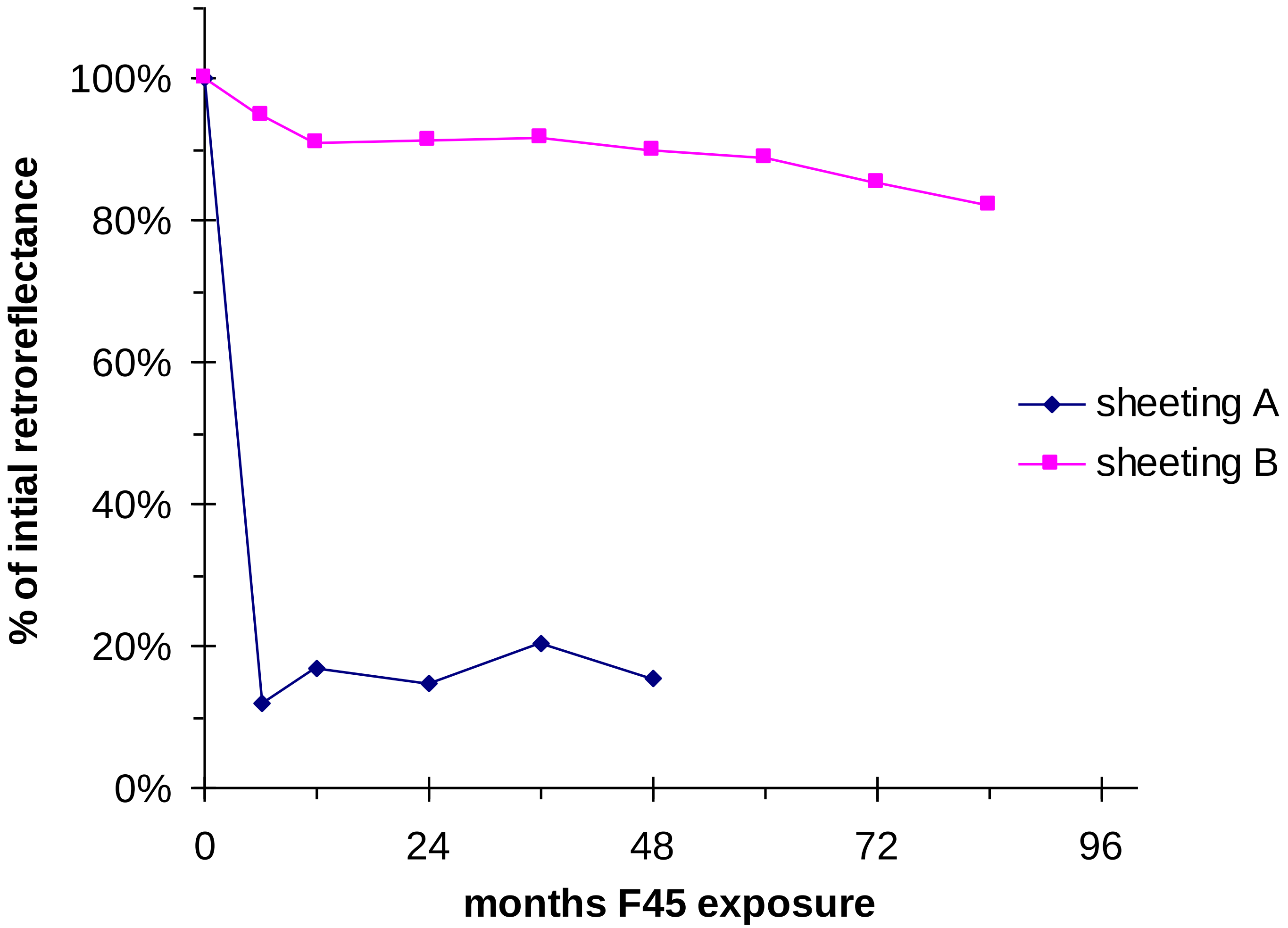
Specifying Retroreflective Sheeting Durability

- **ASTM D4956**
  - Durability requirement based on OUTDOOR exposures
    - 6 to 36 months in tropical summer rain (Miami) and hot desert (Phoenix) climates
    - MINIMUM performance requirement – not an indicator of actual durability
  - Filtered open flame carbon-arc is an optional requirement
    - Proposal to replace carbon-arc with xenon-arc is being considered
- **Other specifications (e.g. EN12899)**
  - Require both accelerated and outdoor exposures
    - Accelerated is xenon-arc
    - Outdoor is not precisely defined
  - Results from outdoor exposures take precedence

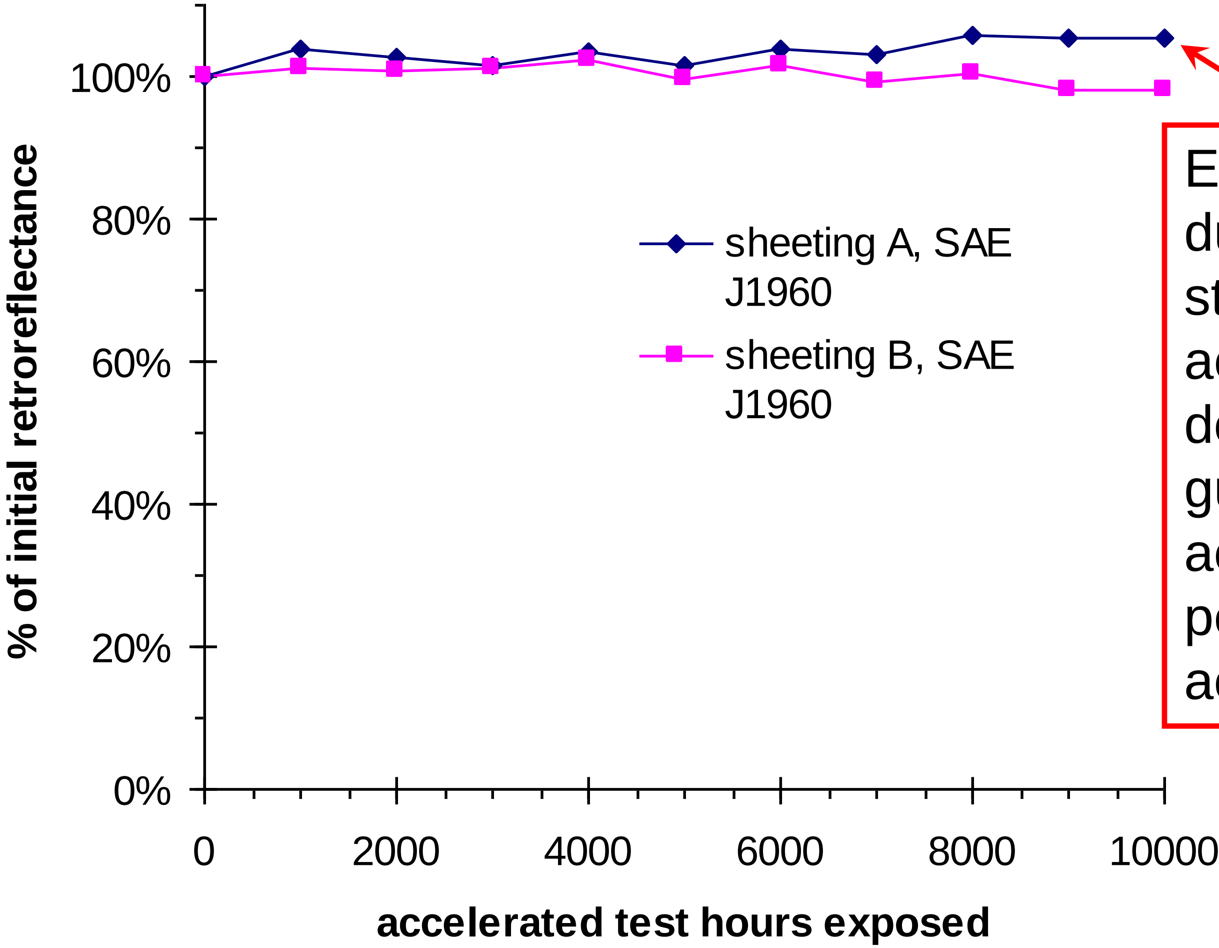
Accelerated Test Development

- **3M has developed several proprietary tests that are superior predictors of retroreflective sheeting durability**

Dramatic Durability Difference Between Two TYPE III Sheetings

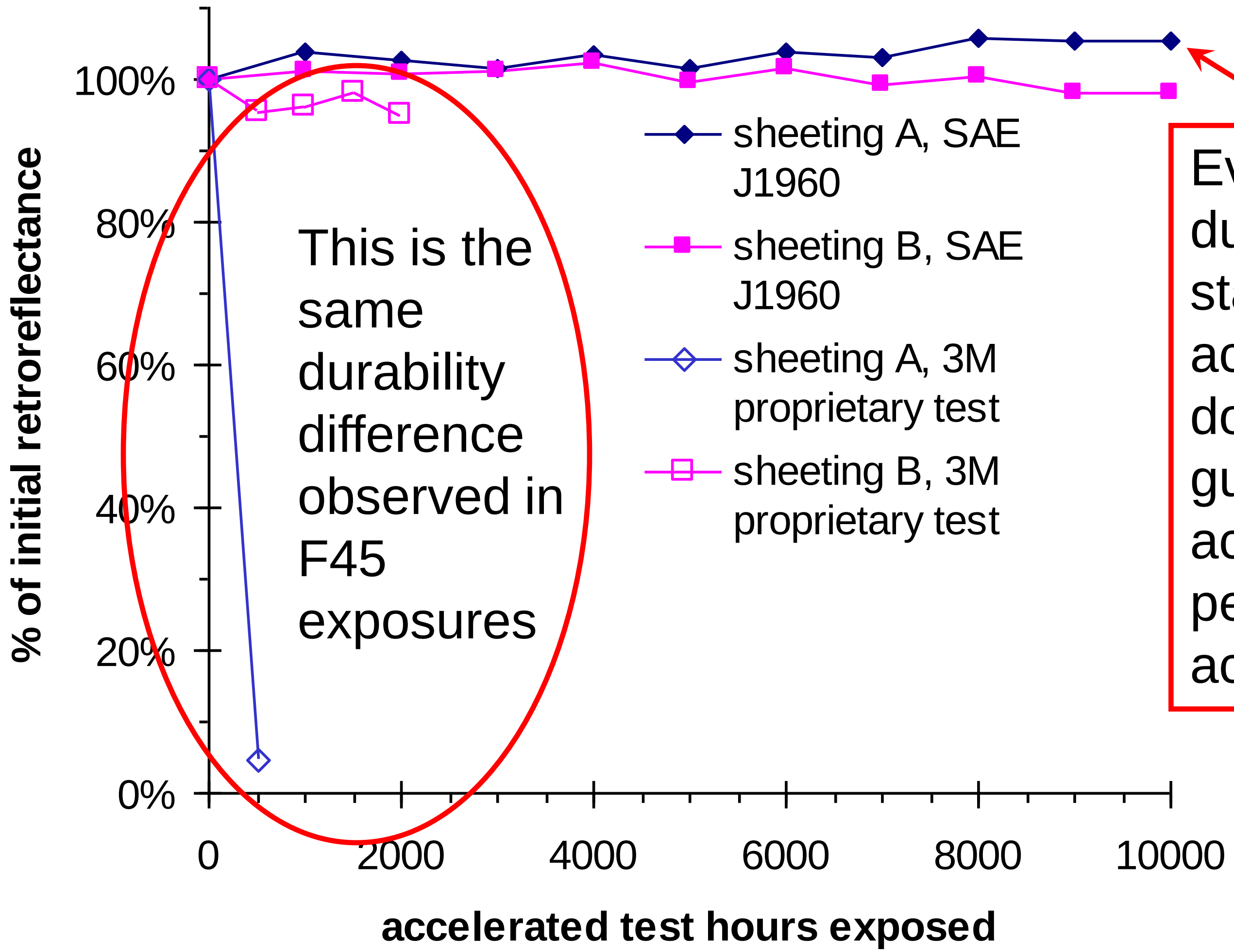


Artificial Accelerated Test Results for the Same Two TYPE III Sheetings



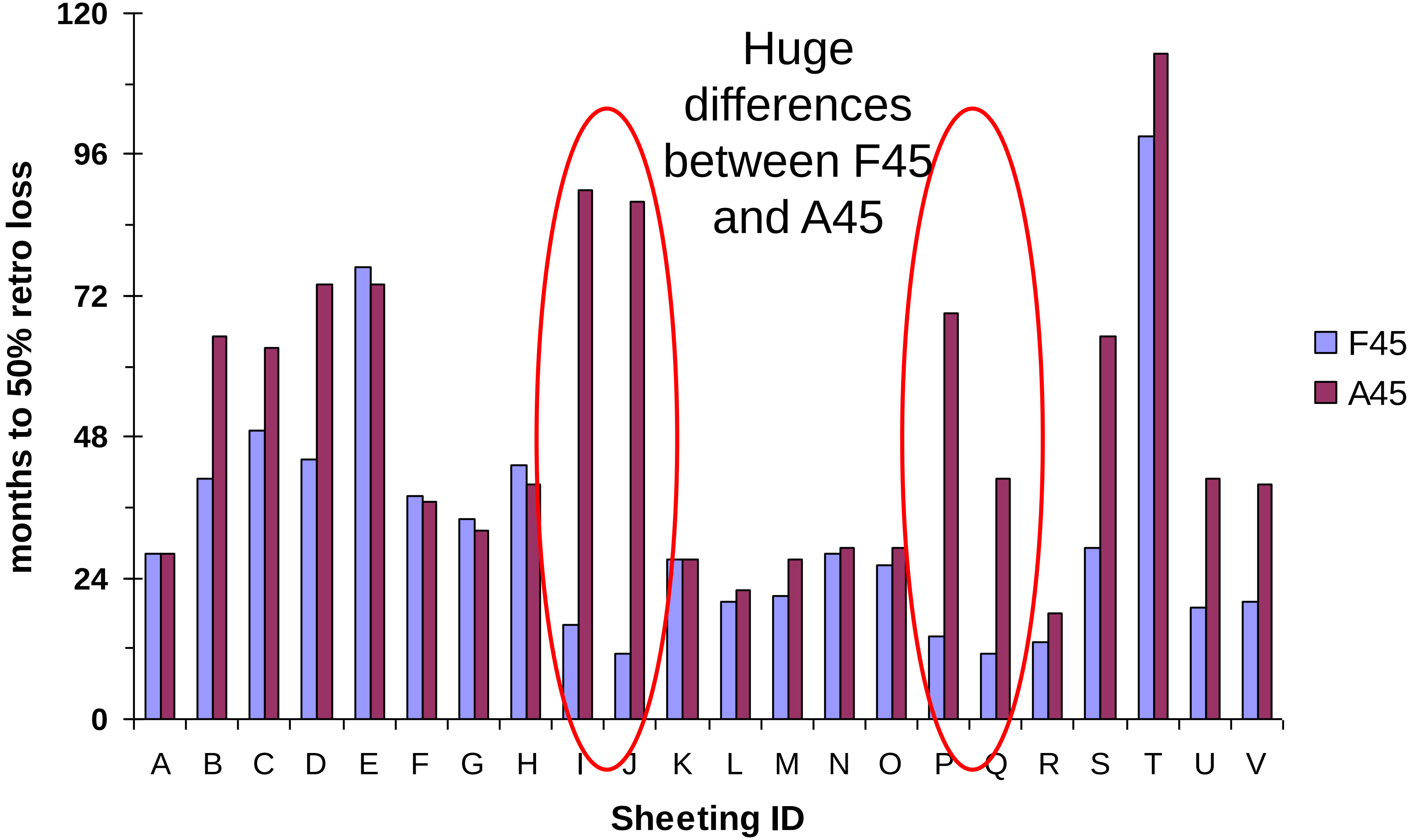
Even exceptional durability in standard accelerated tests does not guarantee acceptable performance in actual use

Artificial Accelerated Test Results for the Same Two TYPE III Sheetings



Even exceptional durability in standard accelerated tests does not guarantee acceptable performance in actual use

F45 and A45 Results for 22 Enclosed Lens Sheetings



Acceleration Factors Show Large Variation

Test Description	Rank Correlation to F45	CV* for AF to 1 year F45	Rank Correlation to A45	CV* for AF to 1 year A45
3M proprietary test #1	0.88	30%	0.29	41%
3M proprietary test #2	0.25	87%	0.76	39%

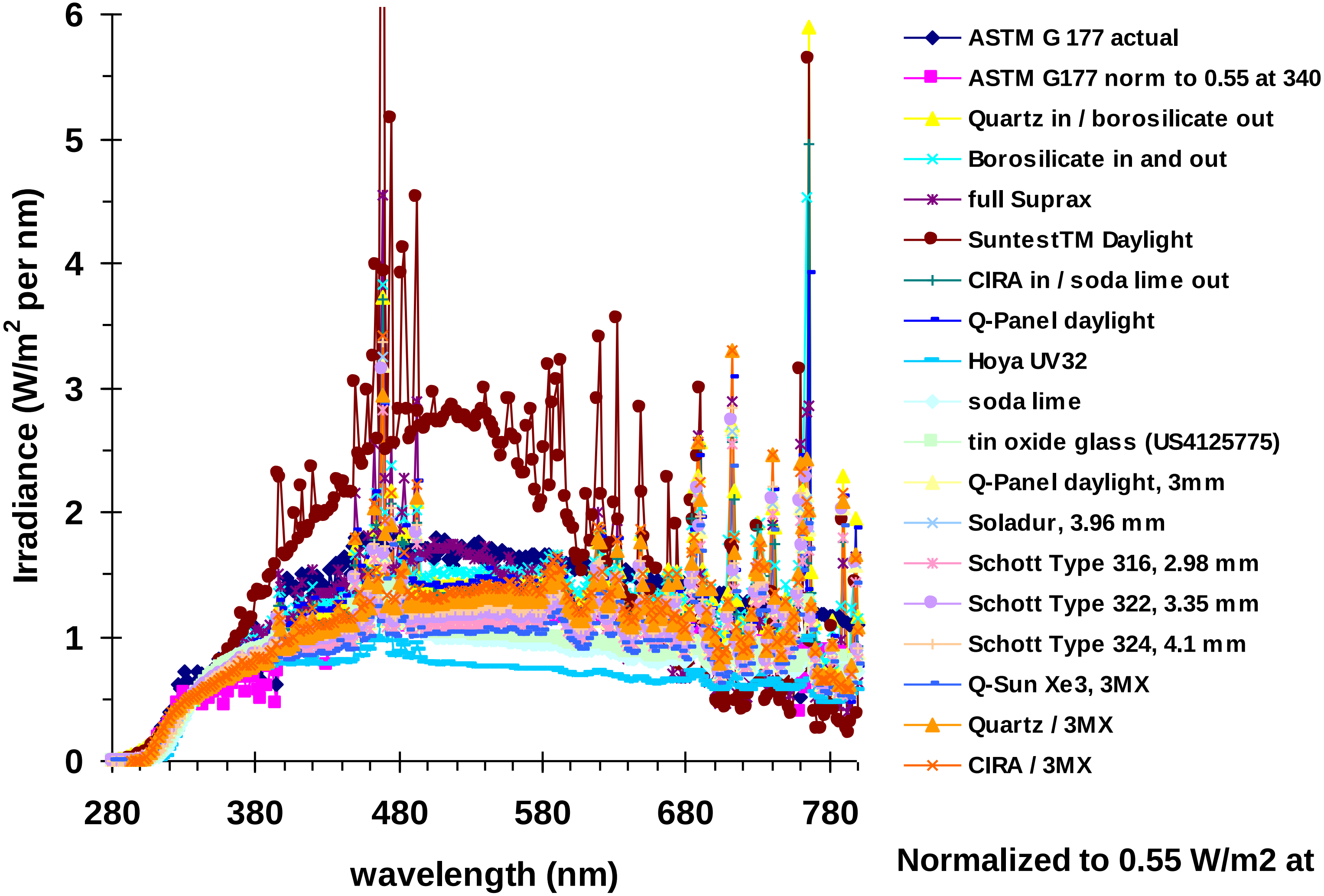
- Rank correlation for F45 to A45 = 0.24
  - Different accelerated tests needed for F45 and A45
- Even tests with good rank correlation to outdoor exposures show huge variability in acceleration factors

*CV = Coefficient of Variance

Accelerated Test Development

- 3M has developed several proprietary tests developed that are superior predictors of retroreflective sheeting durability
- "How to" of this test development taught in ASTM TPT on Weathering and Durability
  - Contact S. Murphy, 610-832-9685
- Light source is critical element in useful artificial accelerated weathering tests
  - Xenon-arc is a good broad-band simulation of solar radiation
  - Too much unrealistic short wavelength UV

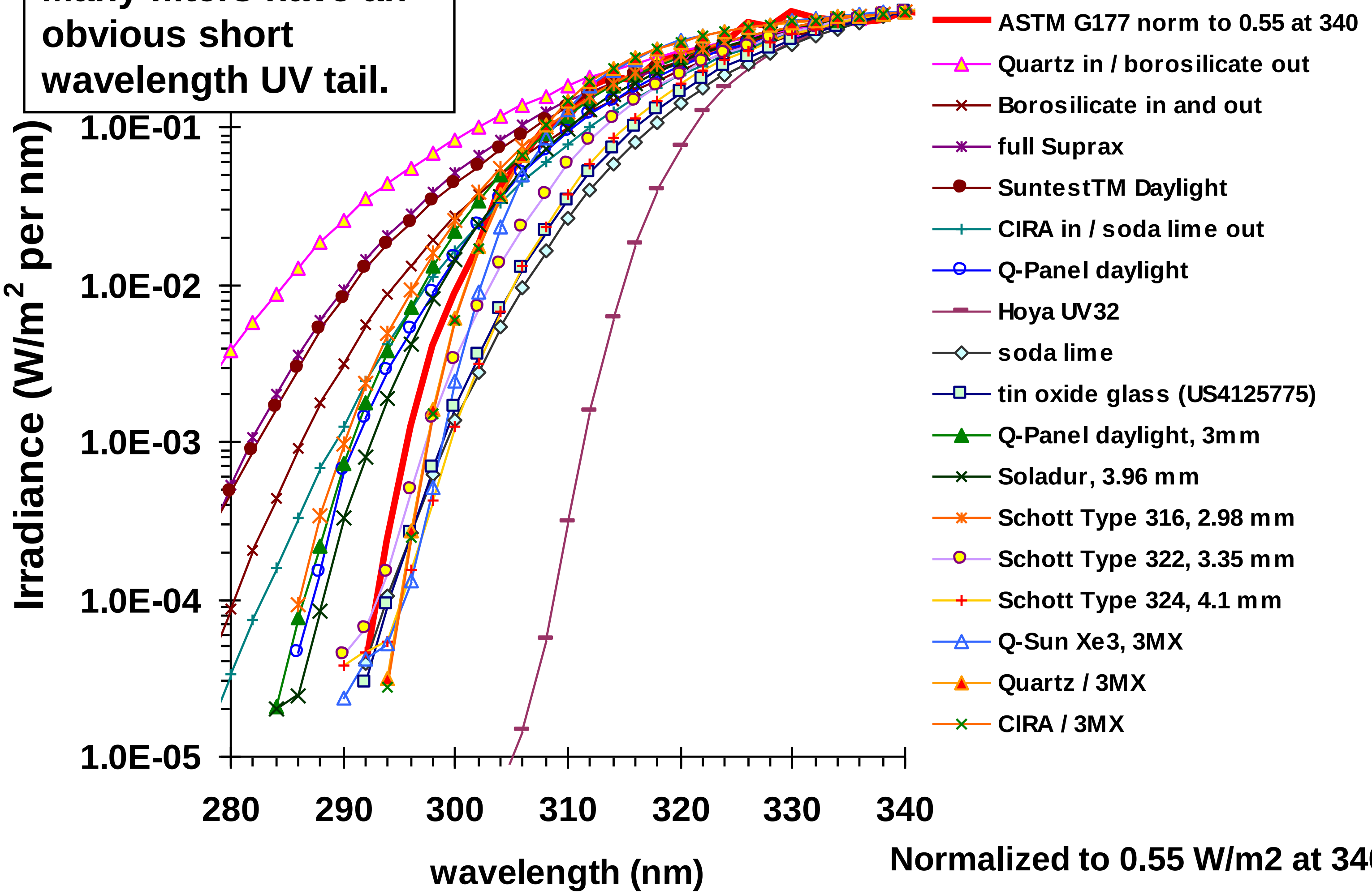
Filtered Xenon-arc Compared to Solar Radiation



Normalized to 0.55 W/m2 at 340 nm

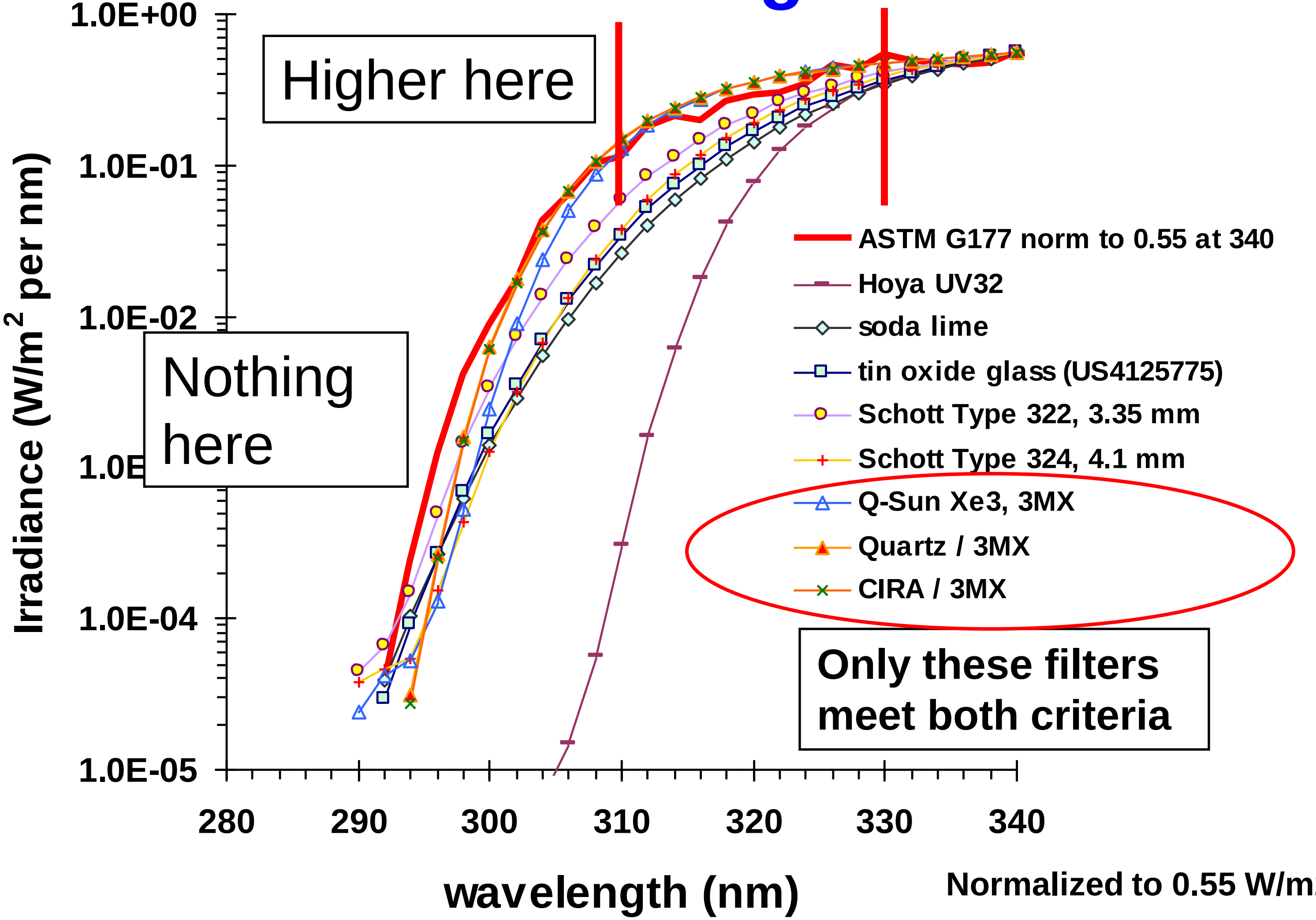
Filtered Xenon-arc Compared to Solar Radiation

Many filters have an obvious short wavelength UV tail.



Normalized to 0.55 W/m2 at 340 nm

Xenon-arc Filters That Eliminate Short Wavelength UV Tail



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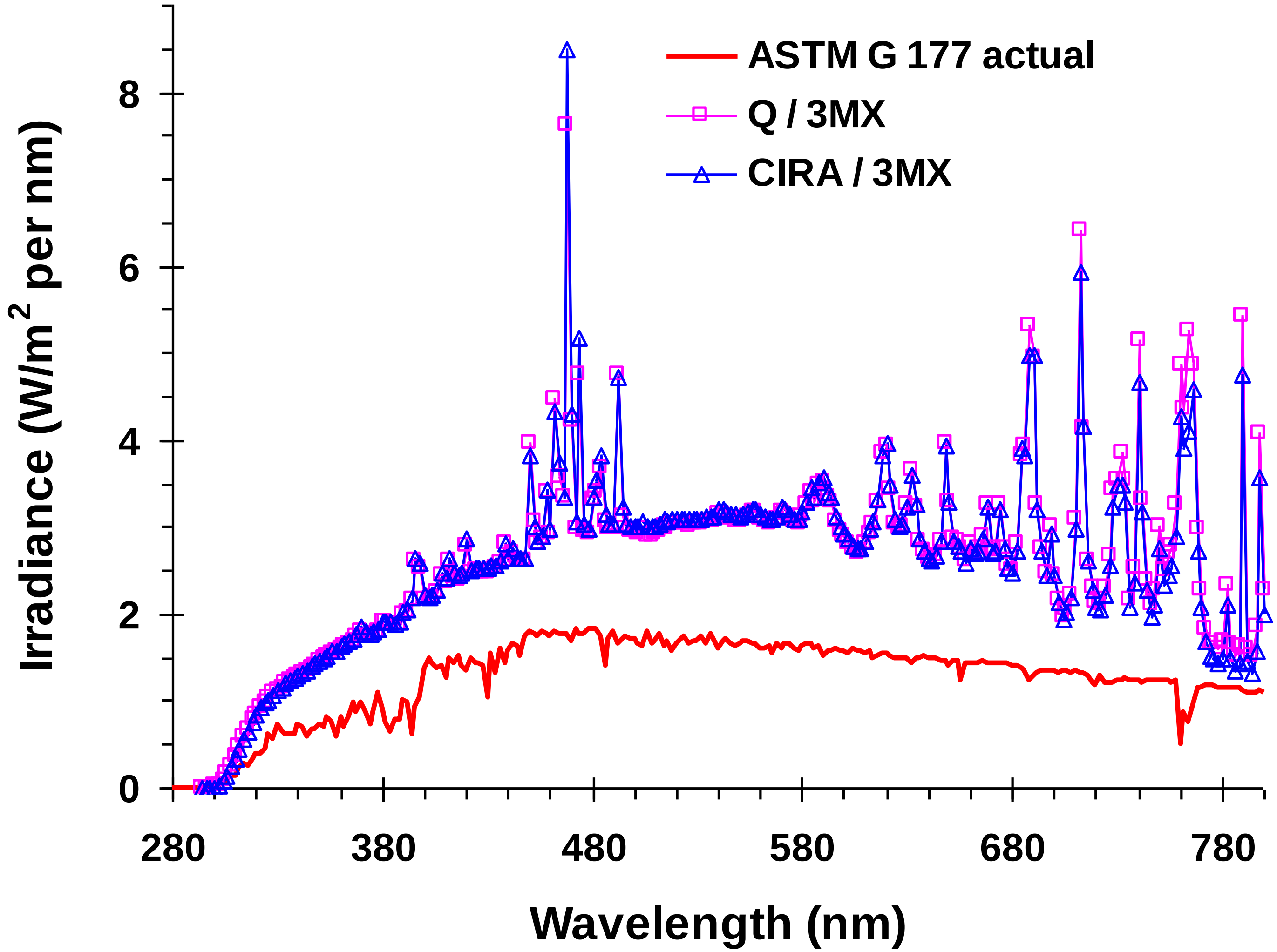
High Irradiance Xenon-arc Exposures Compared to Solar Radiation



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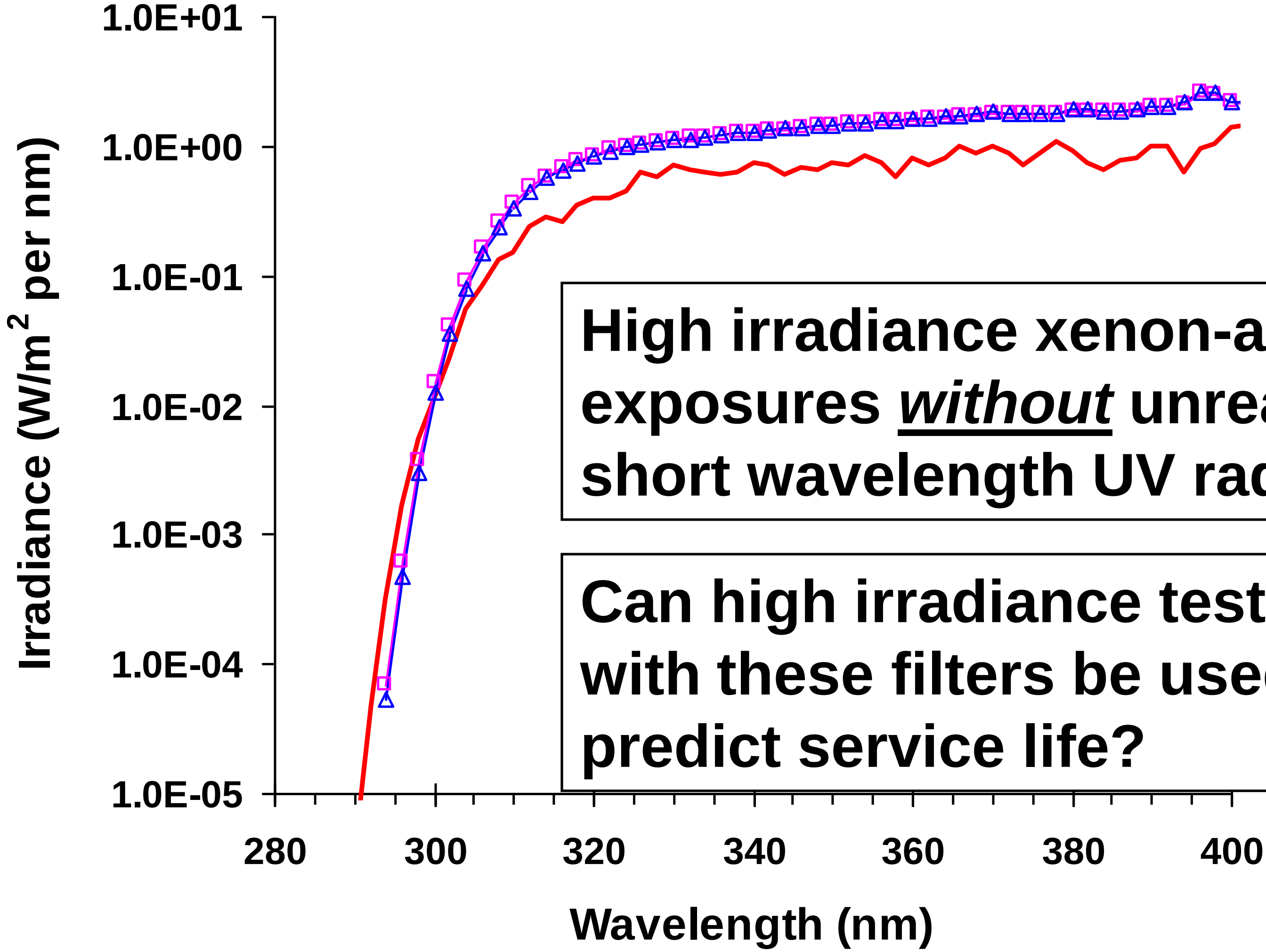


High irradiance xenon-arc exposures *without* unrealistic short wavelength UV radiation.

Can high irradiance testing with these filters be used to predict service life?

Acceleration Factors

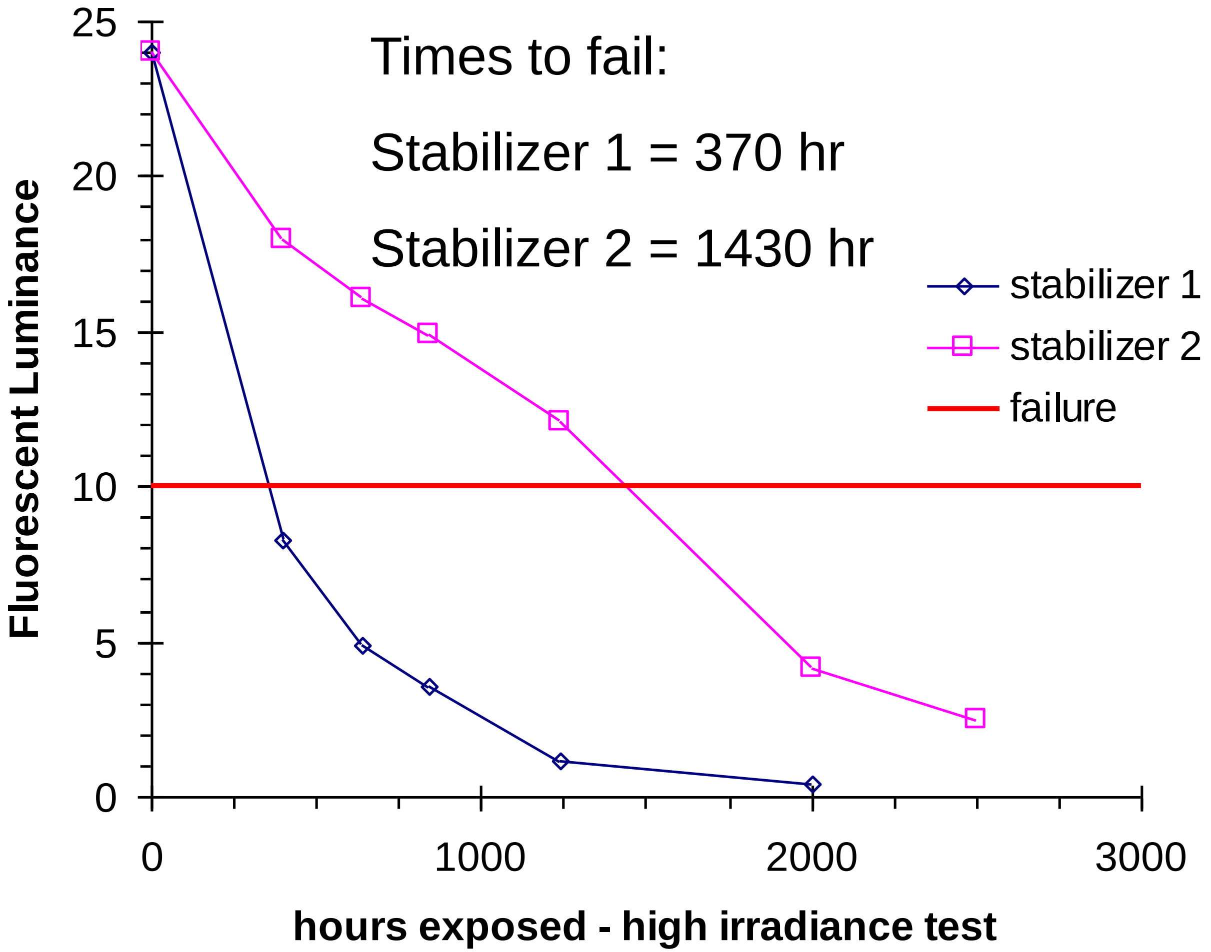
Ratio of time to produce a defined change in a material in outdoor exposure to the time to produce the same change in an accelerated exposure.

$$AF = \frac{t_{outdoor}}{t_{accelerated}}$$

- **24 months Florida 45 exposure to 50% loss of retroreflectance**
- **2000 hr xenon-arc exposure produces 50% loss of retroreflectance**
  - **AF = 8.76** ***or***
  - **1000 hr xenon-arc exposure = 1 year Florida 45 exposure**

Real World Example

Experimental Fluorescent Orange Microprismatic Sheeting



Real World Example

Experimental Fluorescent Orange Microprismatic Sheeting

- **Calculated versus actual outdoor results**
  - Sheeting using stabilizer 1 fails in TX90S at 3.6 yr
  - High irradiance test is 85:1 acceleration
    - 31256 hrs TX90S divided by 370 hr in high irradiance test
  - Sheeting with stabilizer 2 fails in high irradiance test at 1430 hr
  - Calculated failure for TX90S is 13.9 years
  - Actual TX90S fail time for sheeting with stabilizer 2 is 5.0 yr
- **Extrapolated results from high irradiance test dramatically overestimate durability**
- **Why?**

Acceleration Factors are Subject to Material Variability

- **Examples from literature:**
  - **AF's range from 1.8 to 50**
    - **Plastics, coatings, paints, polyolefins**

$$t_{outdoor} = t_{accelerated} * AF_{(light,\ heat,\ water,\ misc.)}$$

- **Since 1997, Focus of 3M weathering research has been on determining material responses to light, heat, and water**

Light Multiplier

- **Power law equation to model material light response**

$$I_{effect} = aI_{actual}^{x}$$

$$\begin{aligned} I_{effect} &= \text{normalized material degradation rate} \\ I_{actual} &= \text{normalized irradiance on specimen} \\ a\,,\,x &= \text{experimentally derived constants} \end{aligned}$$

- **Normalized to maximum irradiance used**
- **If x = 1, reciprocity is obeyed**

Light Effect on Material Degradation

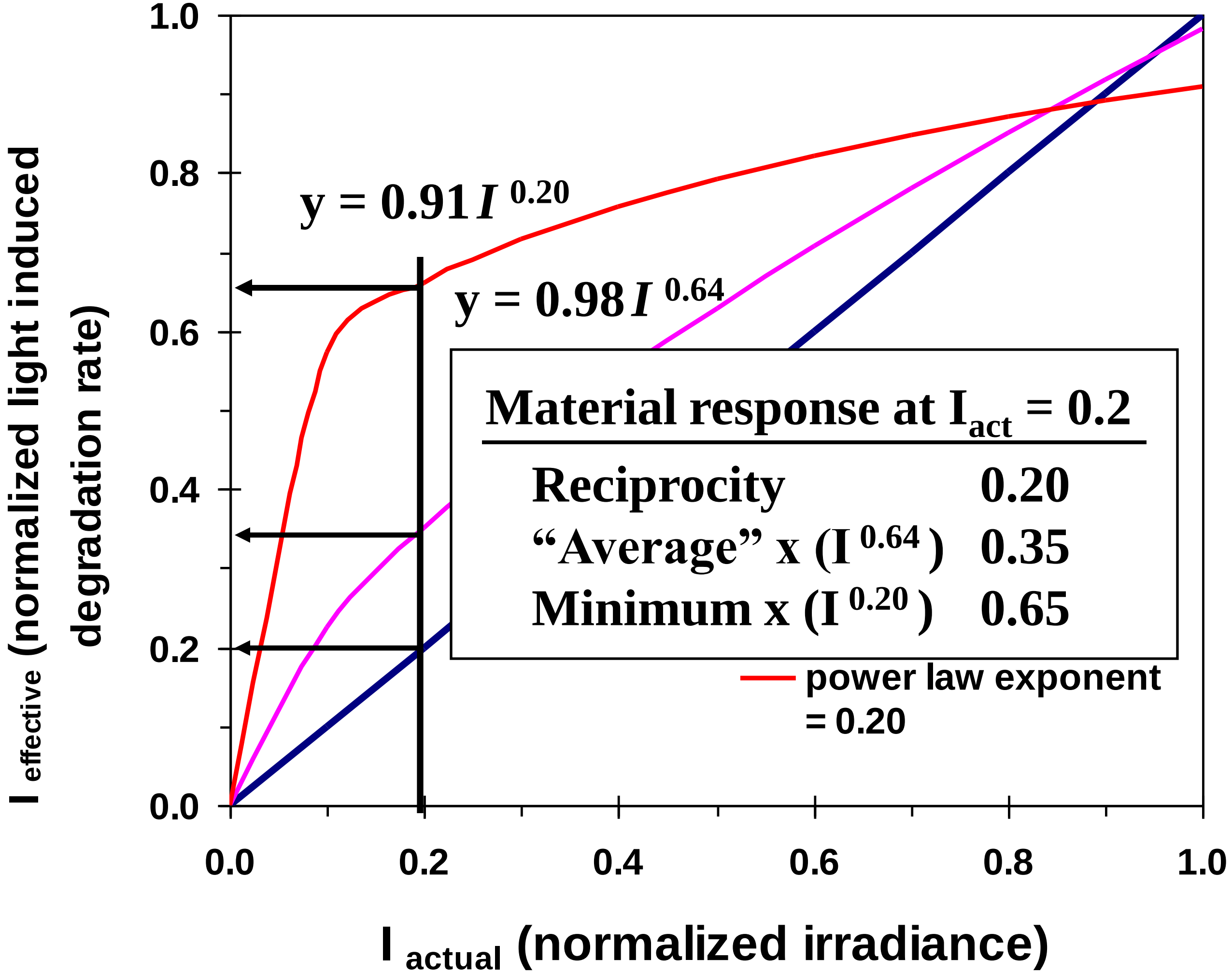
- **Power law exponent for 50 materials**

Parameter	x
Mean	0.64
Standard deviation	0.20
Minimum	0.20
Maximum	1.12

$$I_{effect} = aI_{actual}^{x}$$

- **Reciprocity is the exception**
- **What are the implications?**

Light Effect on Material Degradation



Temperature Multiplier

- **Degradation rate increase per 10 ^{o}C temperature increase**
  - **Determined for 50 materials**

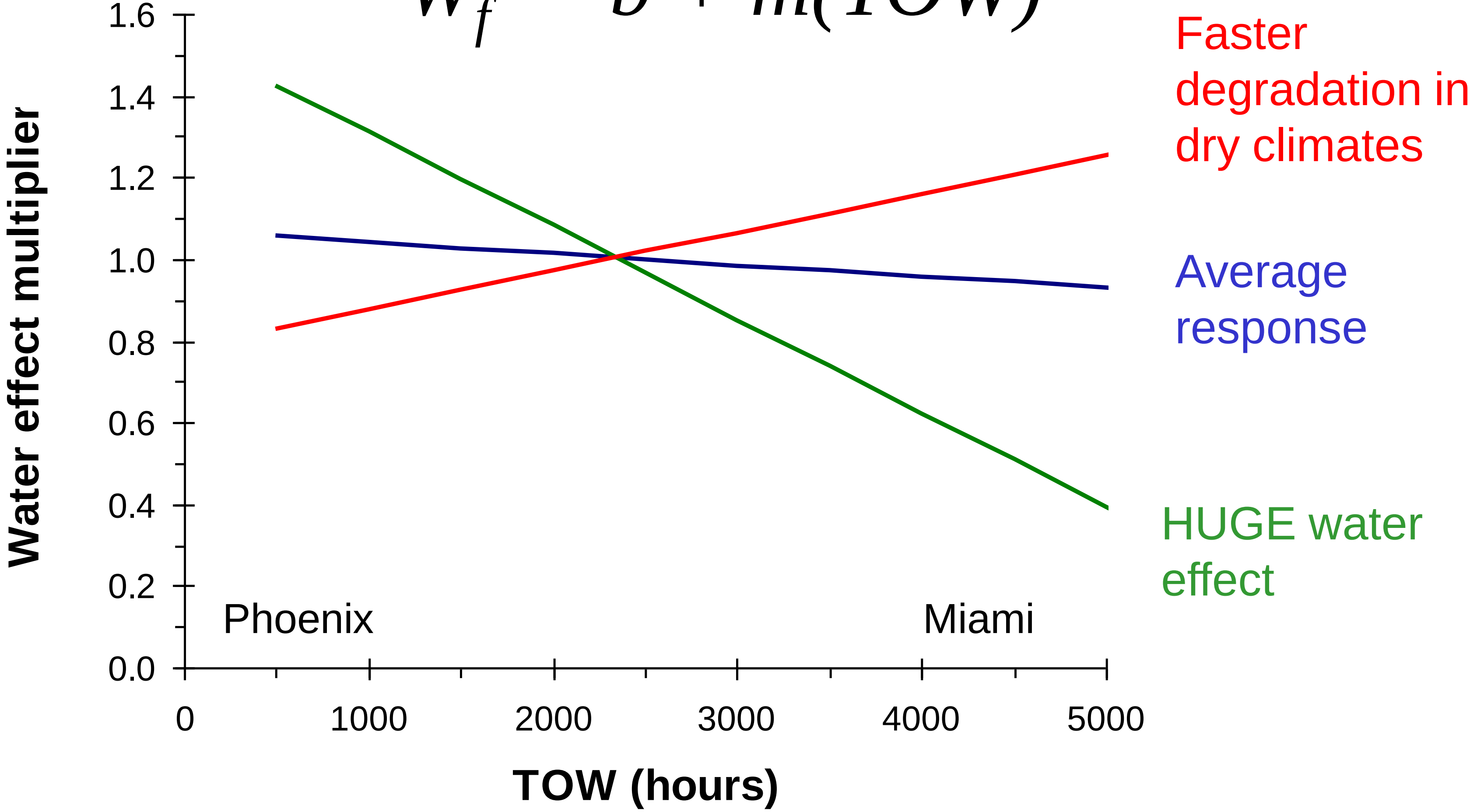
Parameter	T_f
Mean	1.41
Standard deviation	0.23
Maximum	1.89
Minimum	0.97

LESS than the assumed "double the reaction rate for every 10 ^{o}C increase in temperature"

No temperature effect

Water Multiplier

$$W_f = b + m(TOW)$$



Relating Accelerated and Outdoor Failure Times

$$t_1 = t_2\left[\frac{L_2 I_2^x (b) + mTOW_2\left(T_f^{\left(\frac{T_2-T_1}{10}\right)}\right)}{L_1 I_1^x (b) + mTOW_1}\right]$$

- **Power law exponent x, plus constants b, m, and T_f determined experimentally**
  - **3M has determined these parameters for more than 50 materials**
- **Must define light, heat, and moisture stresses in outdoor and accelerated environments**

t_1 = Outdoor test time
t_2 = Accelerated test time
L_1 = Light on fraction outdoors
L_2 = Light on fraction for accelerated test
I_1 = Irradiance in outdoor test
I_2 = Irradiance in accelerated test
TOW_1 = Time of wetness - outdoors
TOW_2 = Time of wetness - accelerated test
T_1 = Temperature - outdoors
T_2 = Temperature - accelerated test
x = Power law exponent

Stresses in outdoor and accelerated exposures

- Light
  - 295-385 nm total UV
    - Outdoor from climate data reported by Atlas Weathering Service Group
    - Accelerated from spectroradiometric measurements
- Heat
  - Surface temperature from: $$T_s = T_a + I\frac{a}{h}$$
  - T_a and I data from Atlas Weathering Services Group
  - Direct measurement in accelerated testing
- Water
  - Time of wetness from climate data or knowledge of accelerated test cycle

Relating Accelerated and Outdoor Failure Times

$$t_1 = t_2 \left[\frac{L_2 I_2^x (1 + mTOW_2) \left(T_f^{\left(\frac{T_2 - T_1}{10} \right)} \right)}{L_1 I_1^x (1 + mTOW_1)} \right]$$

- Determine distribution of possible outdoor failure times from a single accelerated test result

t_1 = Outdoor test time

t_2 = Accelerated test time

L_1 = Light on fraction outdoors

L_2 = Light on fraction for accelerated test

I_1 = Irradiance in outdoor test

I_2 = Irradiance in accelerated test

TOW_1 = Time of wetness - outdoors

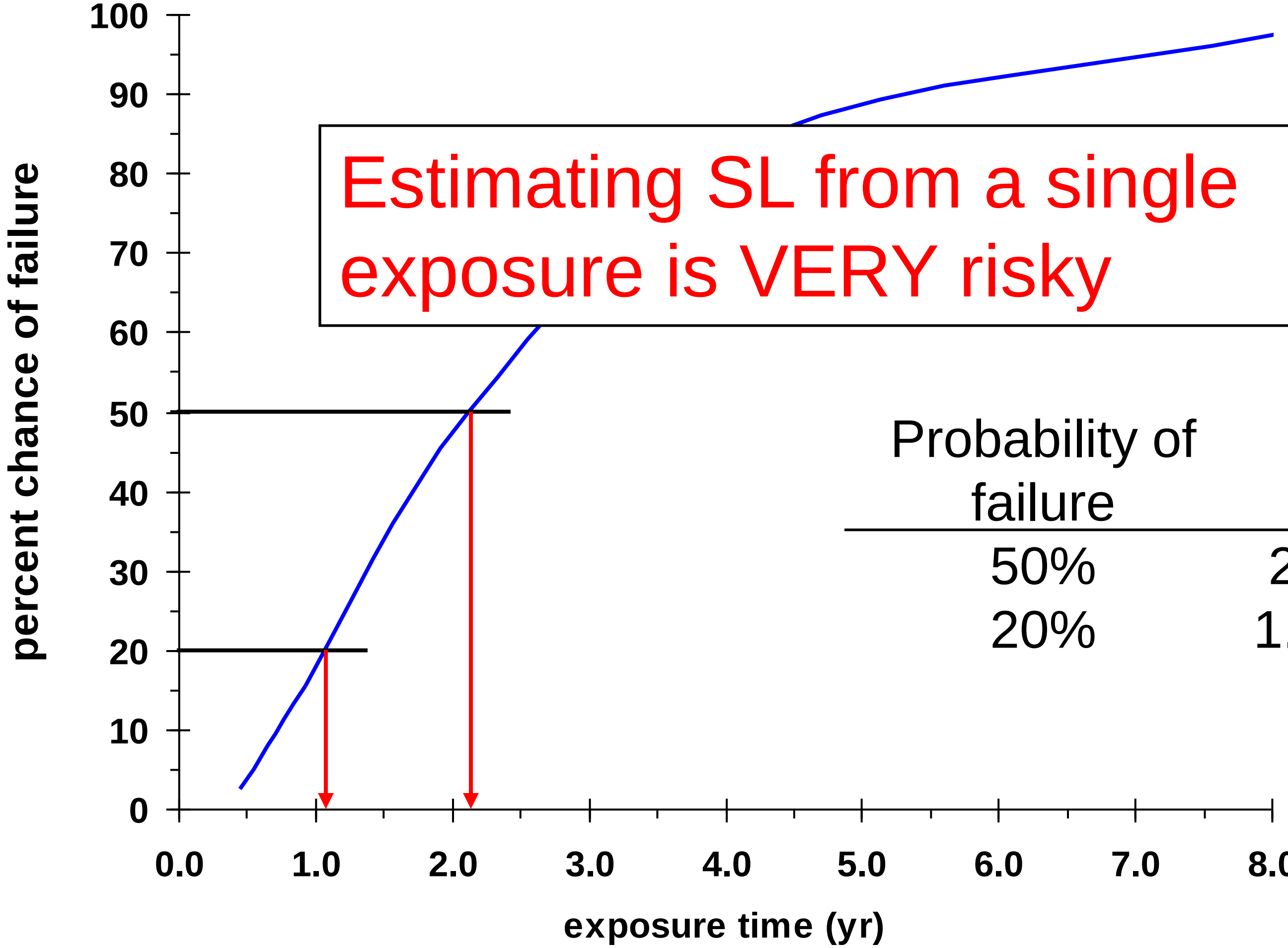
TOW_2 = Time of wetness - accelerated test

T_1 = Temperature - outdoors

T_2 = Temperature - accelerated test

x = Power law exponent

Probability plot for outdoor results based on 3000 hr ASTM G155 cycle 1



Estimating SL from a single exposure is VERY risky

Probability of failure	F45
50%	2.1 years
20%	1.05 years

Conclusions

- Industry standard accelerated weathering tests are poor predictors of retroreflective sheeting durability
- Outdoor exposures are more reliable for specifying minimum durability
- Accelerated tests that provide good rank correlation have been developed
- New filters have been developed that allow a near perfect simulation of solar ultraviolet
- Even in tests that produce good rank correlation, results from single exposures cannot be used to estimate service life
- Service life prediction is possible but requires multiple tests to define material responses to light, heat, and water