Chapter 9
Test Method Development for Outdoor Exposure and Accelerated Weathering of Vinyl Siding Specimens

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Abstract This chapter provides an overview of extensive research conducted by the Vinyl Siding Institute (VSI) on the development of new test methods for exterior plastic building products. The purpose of the VSI study was to develop an accelerated testing protocol for use in certifying materials.

This chapter describes the development of an outdoor certification test program and subsequent efforts to create an accelerated weathering test method that could be used to predict the results of the outdoor protocol with a high degree of accuracy. Outdoor weathering tests were conducted in Florida, Arizona, and the northern temperate locations to obtain baseline data for comparison. This part of the research led to the development and subsequent publication of ASTM D6864.

Accelerated laboratory tests were performed in Fluorescent UV/condensation test apparatus and xenon arc test chambers. The process involved the examination of multiple types of equipment, multiple cycles, and multiple conditions, and comparing the various results to the outdoor exposures. Testing suggested that for this particular material, one method was more suitable than the other. The proposed method was verified with repeat testing and rugged statistical analysis. Round robin testing was conducted to determine repeatability and reproducibility.

Although the proposed accelerated method was not adopted into the VSI's certification program, its results demonstrated high rank-order correlation with outdoor test results, giving the user much greater confidence that materials passing the accelerated test will pass the outdoor test. The accelerated method, therefore, is useful during research and development because it provides a fast and reliable method for evaluating small formula changes. It is useful for selecting formulations to include in a 2-year certification test.

Keywords Service-life prediction • Real-world validation • Degradation pathways • Degradation-rate model • Accelerated life testing • Cumulative damage model • Photodegradation rate • Temperature dependence • Irradiance dependence • Reciprocity • Model robustness

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What Is Vinyl Siding?

Home remodeling and new construction product developers and manufactures are constantly introducing a wide range of new innovative materials and products. Cost, durability, appearance, low maintenance, and variety are the competing characteristics customers seek, with cost gaining importance in a tough economy.

Vinyl siding is industry's response to these needs in the residential cladding market, having been the most widely used material in the United States and Canada since 1995.

Vinyl siding was first introduced in the early 1960s, but didn't start becoming popular until the mid-1970s. Although home remodeling has constituted most of the vinyl siding market historically, new construction now accounts for more than one-third of vinyl siding sales.

Vinyl siding is manufactured by co-extrusion. The lower layer (substrate) is typically PVC, while the top layer (capstock) is the weatherable surface of the siding. Two common capstocks are PVC and ASAs and similar polymers.

PVC offers many advantages over other polymers in siding applications, including cost, flame retardance, and impact resistance to name a few. We will focus on one aspect of durability that tends to be very important to consumers, color retention over the life cycle of the product. Although the warranties for vinyl siding products vary considerably from one manufacturer to another, the color retention warranties typically cover decades of use. Many warranties cover 50 years and offer transfer provisions when homes are sold. Needless to say, potential warranty liabilities represent materially significant costs for manufacturers.

This chapter will focus on the work undertaken by the Vinyl Siding Institute (VSI) over a period of more than 20 years in understanding the weatherability of the wide range of colors offered by its members to the marketplace.

We will review the long-term outdoor test programs undertaken by the VSI and the extensive efforts undertaken in the development of an accelerated laboratory test protocol.

Vinyl Siding Degradation and Color Change

PVC capstock has three main failure modes:

Yellowing: The primary degradation mechanism is dehydroclorination. In this reaction, the C–Cl bond is broken by a photon of UV light, liberating chlorine which can attract hydrogen to form HCl, allowing oxidation of the polymer, cross-linking, and double-bond formation. The dehydroclorination process can be autocatalytic, resulting in polyene sequences. The absorption spectra of polyenes extend from the UV into the shorter wavelengths of visible light (blue), resulting in a yellowish appearance [1, 2].

Fade: The polymers are not photostable without the use of stabilizers. Their degradation mechanism involves the breaking of the double bond and the subsequent oxidation. This results in the formation of large quantities of species like peroxides. These species can have significantly different refractive indices than the PVC, causing scatter at the interface. If enough interferences are present, the resulting scatter will appear as a whitish haze [1, 2].

Chalking: If the yellowing and fading go on long enough, the surface integrity of the polymer can begin to fail, leading to checking, cracking, and flaking of the surface [1, 2].

What Is VSI?

The VSI is the trade association for manufacturers of vinyl and other polymeric siding and suppliers to the industry.

The VSI offers a certification that indicates a manufacturer's specific product meets or exceeds relevant ASTM standards. ASTM D3679, *Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Siding* [3], and ASTM D7254, *Standard Specification for Polypropylene (PP) Siding* [4], cover most product specifications, while ASTM D6864, *Standard Specification for Color and Appearance Retention of Solid Colored Plastic Siding Products* [5], and ASTM D7251, *Standard Specification for Color and Appearance Retention of Variegated Color Plastic Siding Products* [6], are specific to color and appearance.

An independent testing lab is used to insure that a product has been properly tested and inspected for a number of characteristics before it receives the VSI certification. Basic characteristics like length, width, and thickness are verified to insure the manufacturer is providing a product that matches the specification advertised. Other testing is more rigorous, involving testing the performance properties of the siding. Weathering exposures, for example, are conducted in three different locations over 2 years to determine if the siding will retain its color over time, in its intended service environment.

As of January 2013, 14 manufacturers representing 37 brands have products listed on the "VSI Product Certification Program's Official List of Certified Products." These manufacturers have a wide variety of colors, an average of approximately 30 each, on the certified products list [7].

VSI's Outdoor Weathering Testing Program

The outdoor weathering requirement for VSI certification requires 2-year exposures at 45° south facing in three locations: Miami Florida (subtropical), Phoenix Arizona (desert), and Cleveland, Ohio (northern industrial). Specimens are tested according to ASTM D6864; additionally the VSI has an outdoor weathering test protocol that is used in conjunction with ASTM D6864. This protocol covers such items as number of replicates, sample size, mounting requirements, and data collection methods and procedures [8].

The VSI has determined mathematical ellipsoids for sixteen color regions, which are described in ASTM D6864. Hunter Lab, 2° Observer, specular included is used to define the parameters of the color region. These ellipsoids define the amount of acceptable color change after weathering based on visual evaluations of "initial" and "weathered" samples. They are derived by inserting the ΔL, Δa, and Δb for a weathered sample into the ellipsoid equation for the defined color region and calculating the ellipsoid value for the sample. A value less than 1.0 is "inside" the ellipsoid, and the amount of color change is acceptable. A value of 1.1 or greater is "outside" the ellipsoid, and the amount of color change is unacceptable. The concept is similar to the CMC ellipsoid equations developed by the Color Measurement Committee of the Society of Dyers and Colorists and described in AATCC Test Method 173 [9] and ASTM D2244 [10].

For a product to pass outdoor testing it must be free of any obvious mechanical failure such as peeling or cracking and uniform in appearance, and the average ellipsoid value of weathered samples must be less than or equal to 1.0.

One obvious question arises concerning the 2-year outdoor weathering certification test. How is a 2-year test sufficient for a product intended to last for decades on a house? It took decades of outdoor testing to provide VSI and its members with sufficient data to extrapolate long-term performance from shorter term exposures. Products must exhibit an ellipsoid value of less than or equal to 1.0 after 2-year exposures in all three locations in order to receive VSI certification. Large volumes of data collected over the decades show that a material passing this threshold will likely maintain acceptable color retention over the expected lifetime of the product. The following section provides an overview of some of this data.

VSI Outdoor Weathering Studies

As vinyl siding began to grow in popularity VSI determined that it needed long-term outdoor data on the types of materials commercially available at the time. In May 1984 the VSI began VS1W as a 10-year outdoor weathering study with samples on exposure in Florida, Arizona, and New Jersey. In 1994 the New Jersey portion of the test was ended. The program was extended in 1994 for 5 years, and again in 2000. There are currently 344 samples on exposure in Florida and 46 samples on exposure in Arizona. 20- and 25-year data was collected during the summers of 2005 and 2010, respectively. Subsequently VSI has undertaken a new weathering study approximately every 5 years. With VS1W and subsequent outdoor testing programs reading were to be taken at ½-, 1-, 1½-, 2-, 5-, 10-, 15-, 20-, 25-, and 30-year intervals.

VS2W was started in January 1989 as a 10-year program in Florida, Arizona, and Ohio. In 1999 the Florida and Ohio portion of the test was ended. The Arizona portion of the test was resubmitted for another 5 years in 1999 and 2004. There are currently 292 samples on exposure. Data from this study was used to develop the 2-year protocol [11].

VS3W was started in November 1994 as a 10-year program in Florida, Arizona, and Kentucky. In 2004 it was extended for another 5 years. There are currently 366 samples on exposure in Arizona, 750 samples on exposure in Kentucky, and 366 samples on exposure in Florida.

VS4W was started as a 2-year certification study but was subsequently converted to a 10-year VSI study in 2002. A set of readings was taken in 2003, 2005, and 2010, at which time the program was extended to 2015. There are currently 1,524 solid samples and 273 variegated samples on exposure in Florida, Arizona, and Ohio. This group of samples was used as the baseline for the development of an accelerated test protocol that will be discussed later in this chapter.

VS5W was started in 2005 and extended in 2010 for an additional 5 years. The samples put on exposure represent state-of-the-art product being sold at the time the test was begun.

The scope of these studies represents what actually exists on consumer's homes. Additionally, the samples continue to show change over time and the data collected is priceless when looking at warranty and product durability issues. Table 9.1 represents some of the colors on exposure in the four currently running studies. It indicated that after 10 years on exposure 90 % of the samples exposed in Florida and 80 % of the samples exposed in Arizona are still in their color ellipsoid. After 15 years the numbers fall to 80 % for Florida and 64 % for Arizona (whites only).

In 1997 VSI embarked on a 24-month outdoor weathering variability study. Four locations were selected: Louisville, KY; Cuyahoga Falls (Cleveland), OH; Chicago, IL; and LaQue, NC. 32 samples from VS2W were selected for testing, eight each from four color regions: gray, dark beige, light beige, and blue. To this sample set an additional 24 samples from VS2W and VS3W were added for a total of 56. Replicates from the original 32 samples were used in round 1 and round 2 of the accelerated weathering experiments. Additionally the ellipsoid values (EVs) obtained from this test program were used as the comparison EVs for the first two rounds of accelerated testing experimentation. Table 9.2 indicates the average ΔL value for each set of samples tested at all 4 locations, 24 replicates for each sample set.

An interesting outcome from the various outdoor test programs is that Cleveland, Ohio, consistently produces more color change than Florida or Arizona for the VSI's products. For example, during the 24-month variability study, the Cleveland location produced an average EV of >1.0, while the average EV of specimens in Florida was less than 0.20 and Arizona was approximately 0.30. Freeze-thaw conditions and industrial pollutants are the two primary conditions that exist in Cleveland and not in the other locations. For white specimens, Arizona consistently produces more color change due to yellowing of the base polymer as a result of high-UV and high-temperature conditions.

Table 9.1

	South Florida exposure—% in ellipsoids										
Study	Color	#	0.5	1	1.5	2	4	5	10	15	20
VS1W	Green	28	100	96	93	93	93	93	93	86	x
VS2W	Green	27	100	100	82	81	85	89	81	x	
VS3W	Green	30	100	100	100	100	100	93	x		
VS4W	Green	108		100	99	99					
VS1W	Yellow	44	100	98	98	95	93	90	86	80	x
VS2W	Yellow	55	100	100	100	100	95	91	85	x	
VS3W	Yellow	36	100	100	97	100	97	97	x		
VS4W	Yellow	35		100	100	100					
VS1W	White	24	100	100	96	92	100	100	100	83	x
VS2W	White	28	100	100	100	100	100	100	96	x	
VS3W	White	25	100	100	100	100	100	100	x		
VS4W	White	17		100	100	100					
VS1W	Medium beige	17	94	94	82	88	94	88	82	76	x
VS2W	Medium beige	57	100	91	75	67	61	56	42	x	
VS3W	Medium beige	63	100	98	95	98	95	98	x		
VS4W	Medium beige	60		100	98	98					
VS1W	Light beige	13	100	100	100	100	100	100	100	85	x
VS2W	Light beige	18	100	100	100	100	83	100	100	x	
VS3W	Light beige	50	96	98	98	98	98	96	x		
VS4W	Light beige	40		100	100	100					
	Arizona exposure—% in ellipsoids										
VS1W	Green										
VS2W	Green	27	96	96	93	96	93	93	78	x	
VS3W	Green	30	100	100	100	100	100	100	x		
VS4W	Green	108		100	100	100					
VS1W	Yellow										
VS2W	Yellow	55	100	100	96	96	91	91	89	x	
VS3W	Yellow	36	100	100	97	100	100	100	x		
VS4W	Yellow	35		100	100	100					
VS1W	White	22		91	95	77	82	84	86	64	x
VS2W	White	28	43	100	71	100	100	89	89	x	
VS3W	White	25	100	100	92	84	88	80	x		
VS4W	White	17		88	100	88					
VS1W	Medium beige										
VS2W	Medium beige	57	100	95	93	93	89	86	68	x	
VS3W	Medium beige	20	100	95	95	95	95	95	x		
VS4W	Medium beige	60		100	100	100					
VS1W	Light beige										
VS2W	Light beige	18	94	100	94	100	100	100	100	x	
VS3W	Light beige	50	100	100	100	98	100	100	x		
VS4W	Light beige	40		98	100	100					

"x"—pending measurement

Table 9.2 Selected VS4W data

Replicate study 24 month outdoor data			
Target	Mean ΔL	Rank	
18S	−2.60	1	
12K	3.10	2	Data
2B	4.51	3	Range
18H	5.31	4	12.16
17J	6.25	5	
13D	7.54	6	StdDev
16H	9.56	7	3.88

The importance of having this detailed knowledge of various outdoor exposures is that the key to creating an effective accelerated weathering test hinged on correlating to Cleveland results for colored specimens and Arizona for white specimens.

Accelerated Weathering for "Fast-Track" Certification

Although the 2-year outdoor weathering program represents a rapid certification cycle, industry requires faster methods of evaluating new formulations before bringing them to market. In an effort to provide a provisional fast-track approval process, the VSI formed an Accelerated Weathering Task Group (AWTG) in late 2000 whose mission was to develop an accelerated test procedure. VSI's Committee on Certification (COC) set very strict parameters for the acceptance of a fast-track approval protocol. This was a high bar that few accelerated weathering tests have ever met in any industry.

The first parameter was that an acceptable protocol must eliminate or reduce to an extremely low level the chance of a false positive result. Also known as a type I error, a false-positive result is one in which a material would achieve a positive, or "passing," result in the accelerated weathering test but subsequently fail the outdoor test. Secondly, any fast-track test must minimize "extreme false negatives." A false negative, or type II error, is a result in which a material achieves a negative, or "failing," result but subsequently passes the outdoor test. The COC defined an "extreme false negative" to be a result in which a very high performing material in the outdoor test failed in the accelerated test. The COC assumed any fast-track certification test would produce some false negatives, but the goal was to provide the best performing products with the fast-track certification option. An accelerated test that eliminated too many high performing products was of limited use to the VSI.

The task group ultimately conducted seven rounds of tests, numbered 1, 2, 3, 4, 5a, 5b, and 6. The original goal of the early rounds was to identify the best accelerated weathering test for vinyl siding products, defined as the test having the highest correlation coefficient to outdoor weathering data. As the AWTG reached this goal, the COC refined its scope in an effort to create a reliable fast-track certification process.

During the latter rounds, the specimens selected for the accelerated exposures were chosen because they exhibited relatively poor correlation with outdoor results. This meant they were more likely to show up as false positives or false negatives in the pass/fail tests conducted during the latter rounds. In other words, the sample set was intentionally biased in order to focus on improving both the exposure protocol and evaluation methodology.

The results and the evolution of the AWTG's work are described below.

Round 1

The first round of testing was conducted in both xenon and fluorescent UV accelerated weathering devices. For the xenon arc testing, two standard test methods were explored: SAE J1960 utilizing a daylight filter and ASTM G155 cycle 1, also using a daylight filter [12]. Tests were performed in the Atlas Ci65A. The xenon arc tests were to run for 2,000 h. The SAE J1960 test had to be terminated after 1,500 h due to specimen warping. This particular test cycle resulted in significantly hotter vinyl siding profile test specimens than the others, which likely accounted for the warping.

The cycle for SAE J1960, which has been replaced by SAE J2527, is as follows [13]:

- 1:00 Dark + water spray (front and back), 38 °C air temperature, 95 % relative humidity
- 0:40 Light with irradiance set to 0.55 W/m^2 at 340 nm, 70 °C black panel, 47 °C chamber air, 50 % RH
- 0:20 Light + front water spray with irradiance set to 0.55 W/m^2 at 340 nm, 70 °C black panel, 47 °C chamber air, 50 % RH
- 1:00 Light with irradiance set to 0.55 W/m^2 at 340 nm, 70 °C black panel, 47 °C chamber air, 50 % RH

The cycle for ASTM G155 Cycle 1 is as follows:

- 1:42 Light with irradiance set to 0.35 W/m^2 at 340 nm, 63 °C black panel (chamber air and relative humidity not specified)
- 0:18 Light + front water spray with irradiance set to 0.35 W/m^2 at 340 nm, temperature and RH not specified

The fluorescent ultraviolet lamp and condensation (fluorescent UV) test utilized UVA-340 lamps as defined in ASTM G154 [14]. The cycle was 12 h of light at 0.89 W/m^2 at 50 °C, followed by 12 h of condensation at 60 °C. The devices used were the QUV with Solar Eye irradiance control.

Table 9.3 shows the xenon data for ASTM G155 cycle 1 at 2,016 h. Table 9.4 shows the xenon data for SAE J1960 at 1,500 h. 2,000 h data was unavailable due to sample warping, as discussed above. Table 9.5 shows 2,000 h data from the

Table 9.3 ASTM G155 Cycle 1

2,016 h G155 Xenon				
	Mean Δ*L*	StdDev	Rank	Data
2B	−0.44	0.23	2.5	Range
12K	−0.41	0.08	2.5	3.84
18S	−0.21	0.23	2.5	
17J	−0.06	0.12	2.5	StdDev
18H	0.37	0.10	5	1.36
13D	0.93	0.04	6	
16H	3.40	0.09	7	
Pearson correlation = 0.67				

Table 9.4 SAE J1960 (J2527)

1,500 h J1960 Xenon				
	Mean Δ*L*	StdDev	Rank	Data
17J	−0.77	0.05	2	Range
2B	−0.70	0.20	2	3.37
12K	−0.67	0.13	2	
18H	−0.36	0.11	5	StdDev
18S	−0.22	0.33	5	1.19
13D	0.02	0.33	5	
16H	2.60	0.07	7	
Pearson correlation = 0.51				

Table 9.5 (G154, VSI cycle 1)

2,000 h fluorescent/condensation				
	Mean Δ*L*	StdDev	Rank	Data
18S	0.48	0.14	1	Range
12K	2.45	1.59	2	5.97
17J	4.53	1.48	4.5	
13D	4.59	1.73	4.5	StdDev
16H	4.65	1.70	4.5	1.94
18H	4.87	0.13	4.5	
2B	6.45	0.05	7	
Pearson correlation = 0.75				

fluorescent UV. The fluorescent UV test cycle had the best correlation to outdoor weathering data at 2,000 h. To determine if the correlation could be improved, the test was run a second time with an identical sample set, this time to 3,000 h. As Table 9.6 indicates greater correlation was achieved.

Table 9.6

3,000 h Fluorescent/condensation				
	Mean DL	StdDev	Rank	Data
18S	1.03	0.12	1	Range
12K	5.18	0.15	2	7.21
18H	5.90	0.31	3.5	
17J	5.95	0.07	3.5	StdDev
2B	7.91	0.11	5	2.55
13D	8.23	0.22	6.5	
16H	8.24	0.12	6.5	
Pearson correlation = 0.92				

Table 9.7

Pearson correlation	
3,000 h vs. 24-month Ohio	0.78
2,000 h vs. 24-month Ohio	0.60
2,000 h vs. 3,000 h	0.90

Rounds 2 and 3

The fluorescent UV testing performed in round 1 was repeated in round 2, using the same sample set, with, three additional labs participating to verify the results. Round 2 also included one additional sample set. This sample set consisted of specimens that passed VS2W but displayed significant color change—i.e., they were close to failing. This round was also the first attempt to quantify the false positives and false negatives generated by the accelerated test method versus outdoor Ohio testing. Table 9.7 compares 2,000 and 3,000 h data to Ohio outdoor and 2,000 h data to 3,000 h data.

Round 3 used the same fluorescent UV test cycle as rounds 1 and 2 plus one experimental cycle using UVA-340 lamps: 20 h of light at 0.89 W/m^2 at 50 °C, followed by 4 h of condensation at 45 °C. The sample set used was from VS4W. The testing was conducted at two laboratories.

When the data was analyzed, it became apparent that using standard rank-order correlation produced too many false positives, meaning that a sample could pass the accelerated test but fail the 24-month outdoor test. Since the goal of the accelerated weathering task group was to develop a method that would allow fast-track conditional approval for new color formulations, it was deemed unacceptable to have false positives. The market effect of having false positives could potentially result in a product passing the provisional accelerated test and then losing its certification when it failed the mandatory outdoor testing. To producers of vinyl siding, this potential outcome was unacceptable.

No xenon arc exposures were performed in round 2. In round 3, some experimentation was done with xenon arc cycles in an effort to improve correlation. However, no significant improvements arose from these experiments.

The accelerated weathering task group members reevaluated their analysis method. They determined that rank-order correlation between the outdoor and accelerated tests was less important than whether the accelerated test method accurately predicted which samples would pass outdoor testing and which would fail. In an effort to determine this, threshold maximum EVs were used in subsequent testing.

Round 4

Armed with the new direction in how to analyze the data round 4 was begun. This round of testing was conducted in fluorescent UV chambers. 29 colored PVC, 3 white PVC, and 9 colored non-PVC samples from VS4W were tested. The fluorescent UV test method used was identical to the previous three rounds of testing. Four laboratories participated in these tests.

Separately, two of the laboratories conducted additional xenon arc exposures independent of the official round 4 protocol. Among the cycles tested was one designed to be similar to the fluorescent UV method: 12 h of light followed by 12 h of dark plus water spray. Multiple variations of this xenon cycle were used.

The results of round 4 indicated several interesting facts.

1. The xenon test method showed very poor correlation to VS4W outdoor data, despite significant experimentation; see Fig. 9.1. The decision was made to drop further xenon tests from the program.
2. While the fluorescent UV test method was run to 3,500 h, substantial color change took place in the first 1,500 h.

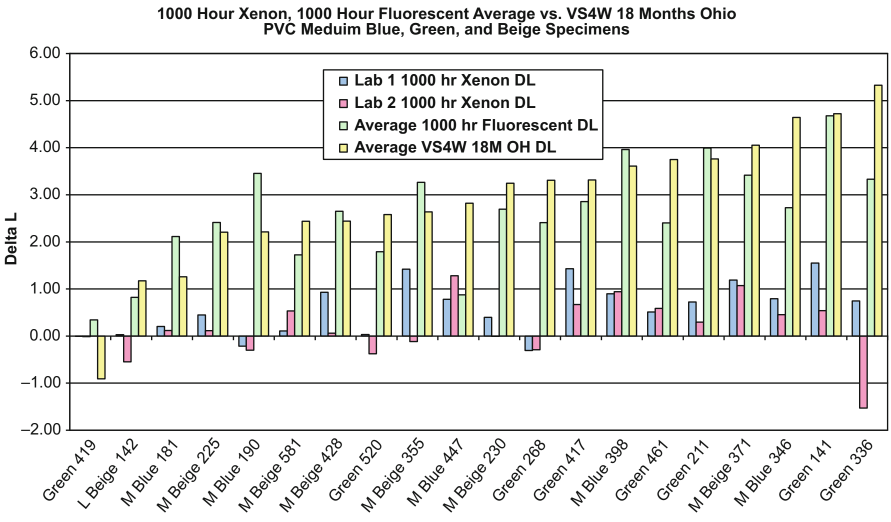

Fig. 9.1

Table 9.8 1,500 h fluorescent UV exposure ΔE Student's *t*-test results

	Accelerated and outdoor		
	Results agree	Results disagree	
Outdoor failures	93.40 %	6.60 %	
38 comparisons			(False positives)
PVC vs. PVC Ref.			
Outdoor passes	90.50 %	9.50 %	
21 comparisons			(False negatives)
Non-PVC vs. PVC Ref.			

3. The correlation to outdoor tests for non-white PVC samples was very good, but the white samples did not weather the same as they did in the Arizona outdoor testing (hot and dry).
4. Though the overall correlation was very good, over 90 % (see Table 9.8), it was determined that the number of false positives was still too high.

Round 5, A and B

To address what was learned during round 4, round 5 consisted of 2 different fluorescent UV test cycles. The first 12 h of light at 0.95 W/m^2 at 50 °C followed by 12 h of condensation at 60 °C, for 3,000 h. The second cycle, to simulate the hot dry climate that is harshest to white siding products, was continuous light at 0.95 W/m^2 at 50 °C for 1,800 h. Samples for the round 5 initially consisted of the following:

VSI accelerated weathering round 5A specimens			
	Colors	Whites	
Round 4 VS4W PVC failures	1	1	
Round 4 VS4W PVC passes	7	1	10 PVC repeats for round 4
New PVC specimens	8	5	13 new PVC specimens
New non-PVC specimens	15	2	17 new non-PVC specimens
Total	31	9	40 total specimens

After further review it was decided to add additional samples and break round 5 into two parts. Round 5A tested the above samples; round 5B would test additional samples.

Repeats from round 5A	8
Repeats from round 4	15 (not included in round 5A)
New untested colors	9 (not included in round 5A)
Total	32

Seven labs participated in round 5A. In an attempt to insure that no false positives would occur, an EV of 0.90 after 3,000 h of condensation/light and an EV of 1.50 after 1,800 h of continuous light were set. For a sample to pass the accelerated testing, all replicates from both tests must pass. As always, three replicates of each sample were run in both test cycles.

The results of round 5 indicated the following:

1. After 900 h of continuous light, significant color change had occurred. Round 5A/continuous light was terminated, and color measurements were taken.
2. It appeared that the 2,000 h data from the round 5A/light-condensation test might be as useful as the 3,000 h data allowing for a shorter test.
3. False positives were not completely eliminated. A dark red specimen that had failed in Ohio and Florida passed the accelerated test.

Round 6

A final set of adjustments was made to the fluorescent UV test cycle in an attempt to eliminate the false positive and reduce the number of extreme false negatives. Temperatures in the condensation function were decreased. Each of the following cycles was run in four laboratories:

Step 1: Condensation for 12 h at 50 °C or 55 °C
Step 2: UV for 12 h, 0.95 W/m^2 at 50 °C (UVA-340 lamps)
Step 3: Return to Step 1

A total of 43 specimens, 3 replicates each, were tested in each cycle. Most specimens were repeats from round 5. This set included all of the specimens whose accelerated testing results were considered extreme false negatives based on earlier rounds of tests. Evaluations were completed at 2016 and 3,000 h. Most change was seen by 2,016 h, as evidenced by results from a reference gray siding profile specimen (Table 9.9). Furthermore, tests run at 55 °C exhibited more color change versus those run at 50 °C.

While the cycle with the 55 °C condensation temperature did improve correlation by reducing the number of extreme false negatives, it did not eliminate the single false positive experienced in previous rounds, as seen in Table 9.10. The passing EV was set at 0.35 to achieve the best match to the outdoor results.

Table 9.9 Reference gray ΔL

	50 °C condensation	55 °C condensation
2,016 h	2.59	5.14
3,000 h	2.90	5.67

Table 9.10

Accelerated passing EV ⟸	0.35	
	Outdoor fail	Outdoor pass
Accelerated pass	1 (2 %)	18
Accelerated fail	16	8 (19 %)

Based on these results, the AWTG determined that the risk of producing a false positive in this accelerated test protocol was approximately 2 %. The risk of false negatives was approximately 19 %. It is important to note that each round of testing narrowed the specimen set to those considered the most problematic for the accelerated tests, creating a bias in the data away from high correlation. Round 4 showed greater pass/fail correlation than round 6 due to this bias.

Conclusions and Discussion

The use of accelerated weathering testing for product certification is a significant, even daunting, technical, and managerial challenge. The VSI overcame many of the technical challenges through a 6-year regime of accelerated weathering tests. It created a novel test cycle in a standard fluorescent UV and condensation weathering device that achieved high correlation with outdoor weathering and correctly anticipated the pass/fail results of the 2-year certification test more than 90 % of the time. Despite this technical achievement, the managerial risk to the VSI was too great and the decision was made not to include a fast-track, accelerated test in its certification program.

Although the project failed to meet VSI's objectives, this work provides many insights into accelerated weathering. Some of these lessons are discussed below.

1. Through examining different outdoor test locations, different accelerated weathering lab techniques and equipment, coupled to the development of realistic evaluation tolerances, a robust accelerated test method can be developed that will predict outdoor weathering results with a high degree of confidence. However, this study proves that significant resources, managerial attention, and patience are required to achieve this result.
2. For PVC siding products, temperature and moisture have a significant synergistic effect on photodegradation. For colored specimens, inclusion of moisture in the accelerated test was necessary to match the outdoor test results from Ohio. For white specimens, replicating the Arizona environment was critical.
3. Matching the sunlight spectrum in the long-wave UV, visible, and IR regions was NOT a significant factor in replicating outdoor test results for PVC-capped siding. If these regions of the spectrum were a significant factor in the weathering of PVC-capped siding, one might have expected xenon arc weathering chambers to have produced better correlation than these results indicate.
4. Reducing accelerated weathering test temperatures was a key breakthrough in obtaining high correlation to outdoor results. Most fluorescent UV test cycles run at 60 °C in the UV function. VSI found that reducing this to 50 °C significantly improved correlation. Even though xenon correlation was lower overall, the test cycle run at 63 °C black panel temperature outperformed the cycle run at 70 °C black panel temperature. In fact, the test at 70 °C resulted in unrealistic warping of specimens, which can occur when unstabilized PVC temperatures

rise above 70 °C. High dosages of IR radiation, which is typical of xenon arc exposures, combined with the insulating characteristics of PVC specimens, appear to result in unrealistic specimen temperatures in xenon arc tests.

5. The cycle which provided the best correlation with the 2-year outdoor results was the following:

   Step 1: Condensation for 12 h at 55 °C black panel temperature.
   Step 2: UV for 12 h, 0.95 W/m^2 at 50 °C black panel temperature with UVA-340 lamps.
   Test time: 2,016 h

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Information on the Vinyl Siding Institute can be found on their website, www.vinylsiding.org.

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