TPO Membranes – Why Performance Matters

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Roadmap…Where We're Going

- TPO Membranes in the Marketplace
- ASTM, TPO Membranes & 10 Years of Testing
- Sampling & Testing – a Comprehensive Approach
- Results
- Recommendations

Let's Step Back …

and Check Where We've Been

1980's — TPO Introduced

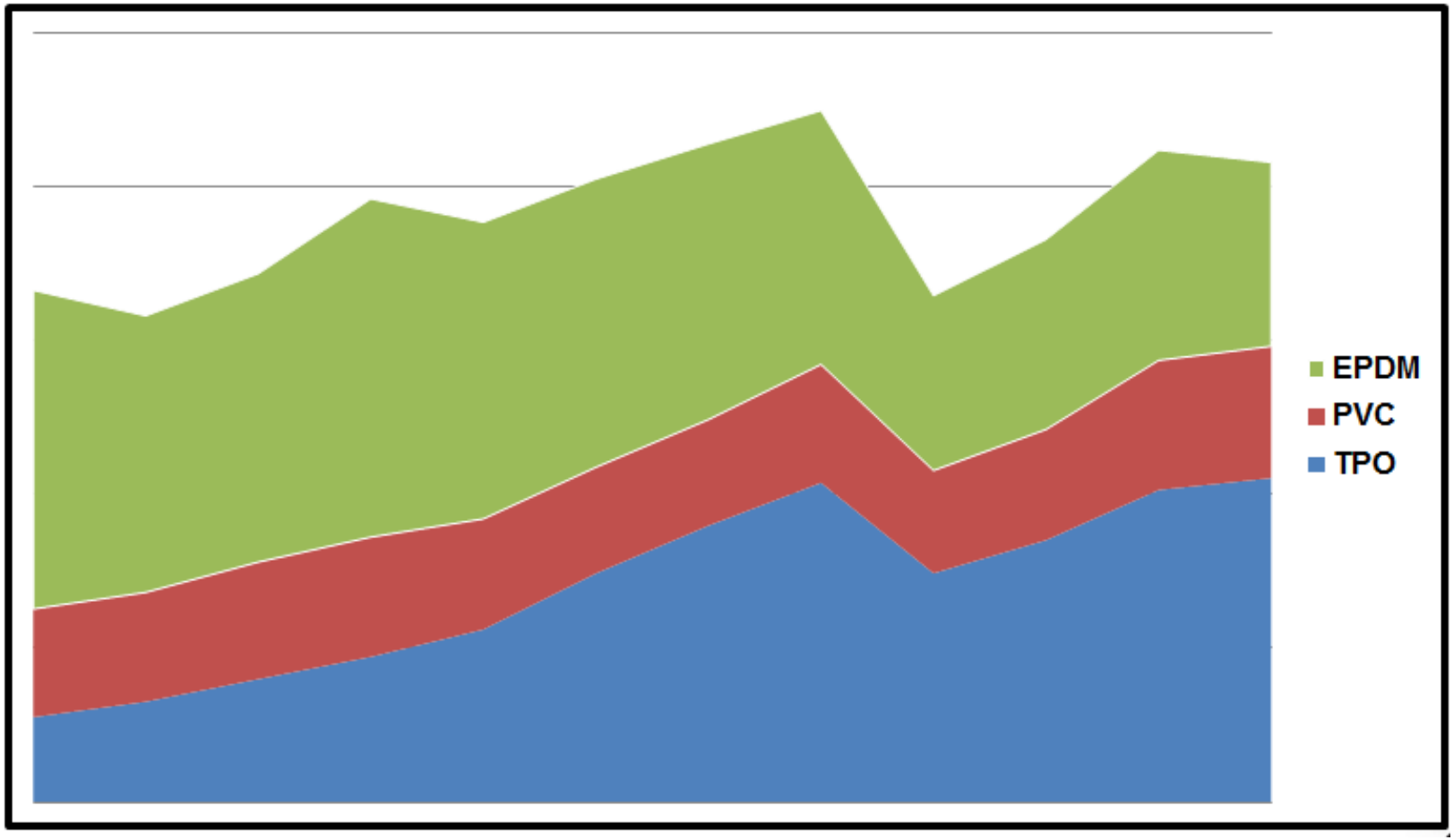
1990's — Reinforced Sheets

2001 — SPRI Separates TPO Out

2008 — TPO Sales 1B Sq.Ft.

2015 — TPO > 50% of SP Mkt

History of Use in the Market Place…2001-2014



1 Billion sq.ft installed every year.

~25,000 miles of welds – that's once around the Earth!!

TPO in 2015…

What Does ASTM Tell Us…
About TPO Membranes?

- Thickness
- Brittleness Point
- Dimensional Stability
- Seam Strength
- Breaking Strength * Elongation * Tearing Strength
- Retention after Heat Aging
- Accelerated Aging

And Like the Product…

D6878 Has Been Evolving

Perceptions of ASTM…

Over the Past 10+ Years…

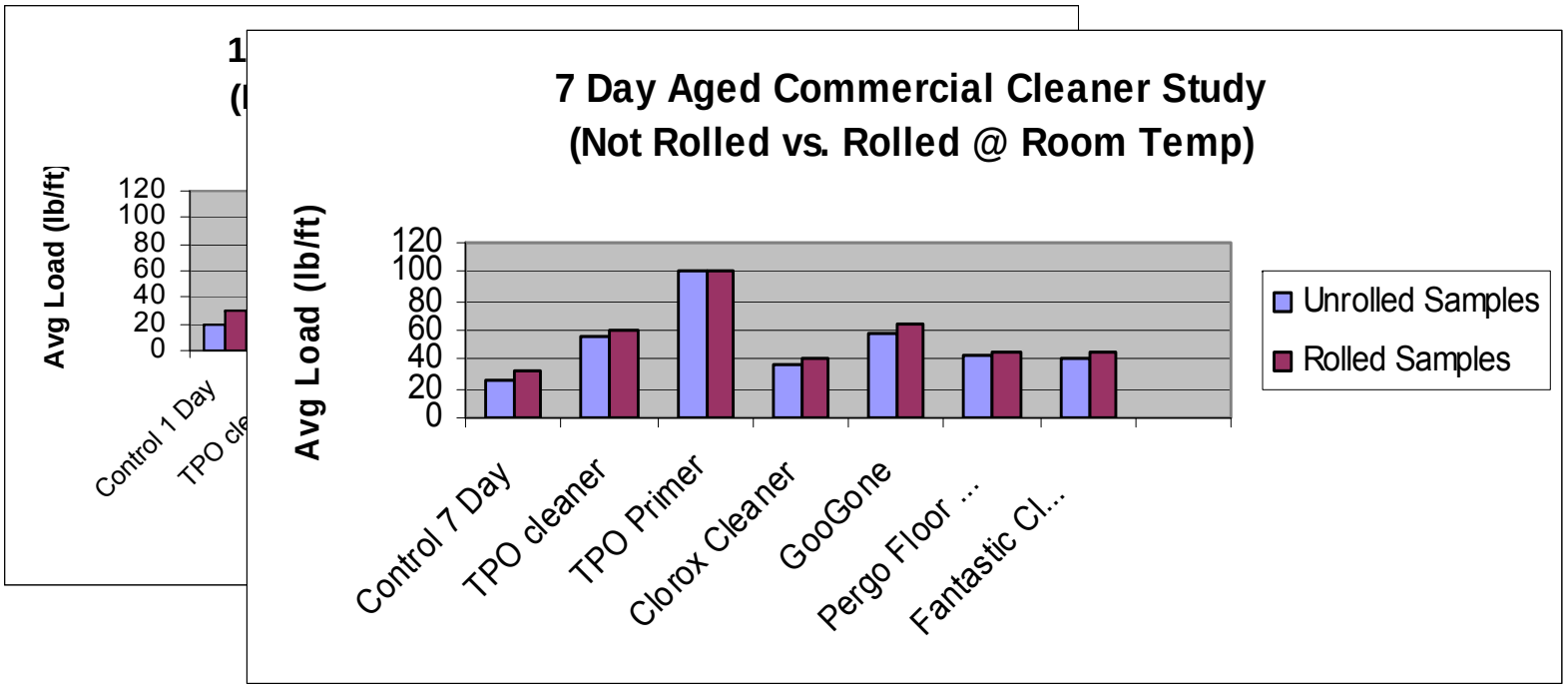
We've Really Tried to Put Product Through Some Paces

And Bought A Lot of Ovens…

We've Listened to Concerns…

For Self Adhering Seams…

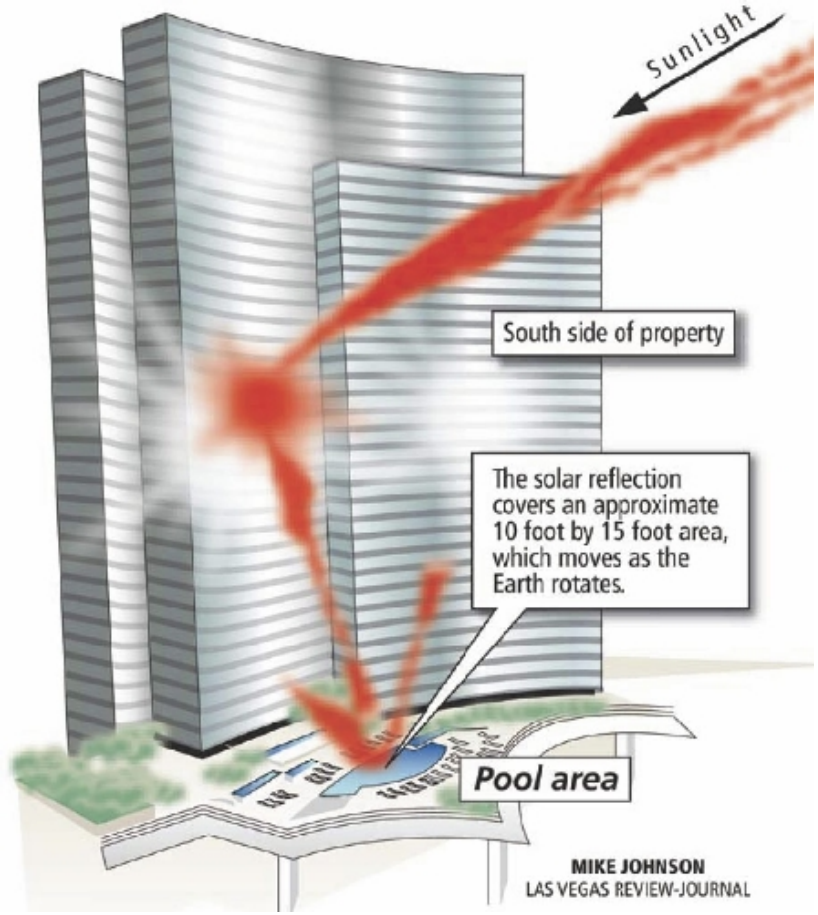
does the cleaner/primer make a difference?



And We've Welded a Lot of Seams…

And Pulled Apart Just as Many…

We've Examined Temperature Concerns…



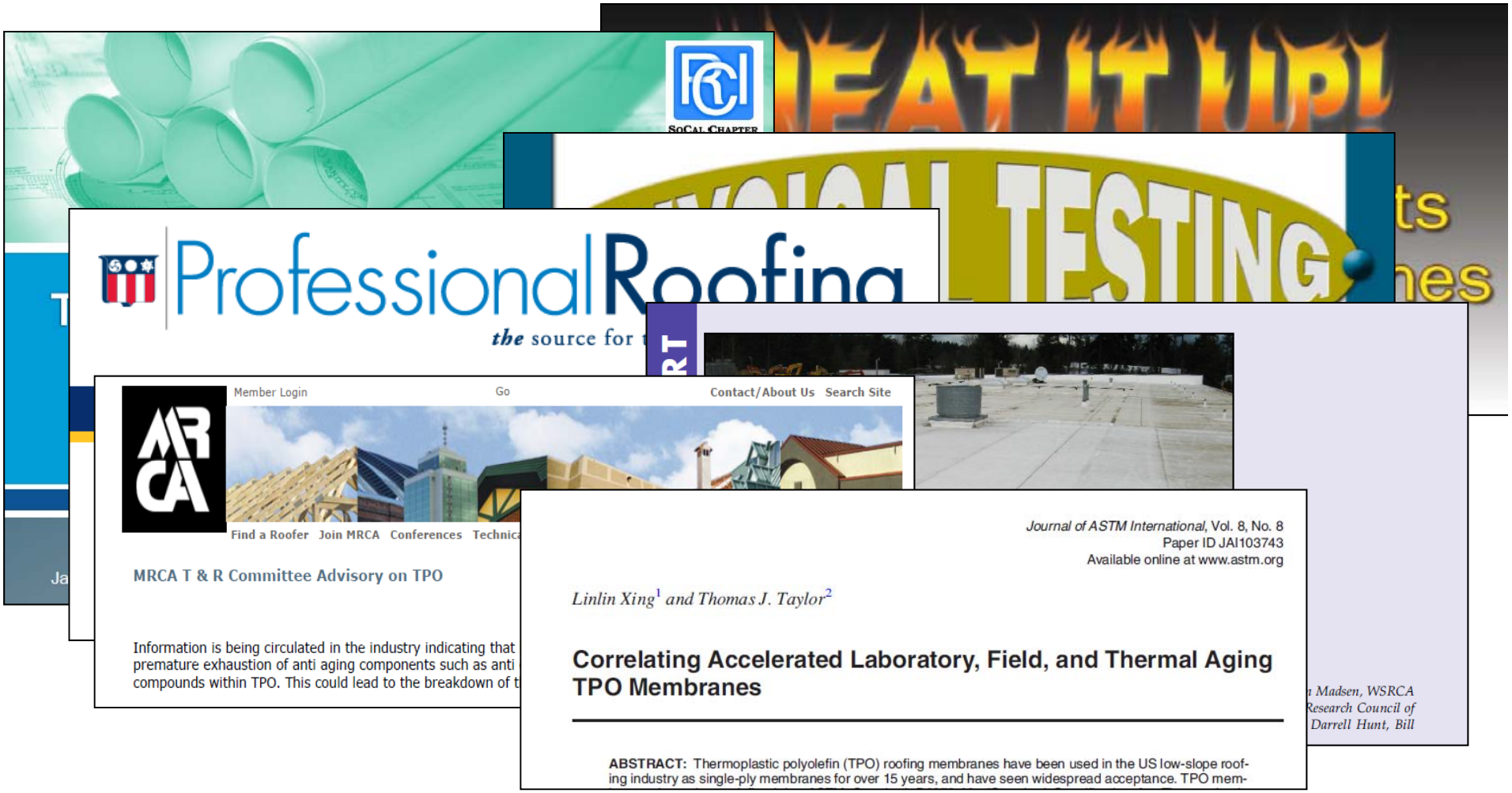
We've Tested In Situ Temperatures

Just because it's white doesn't mean that it is ALWAYS cool…

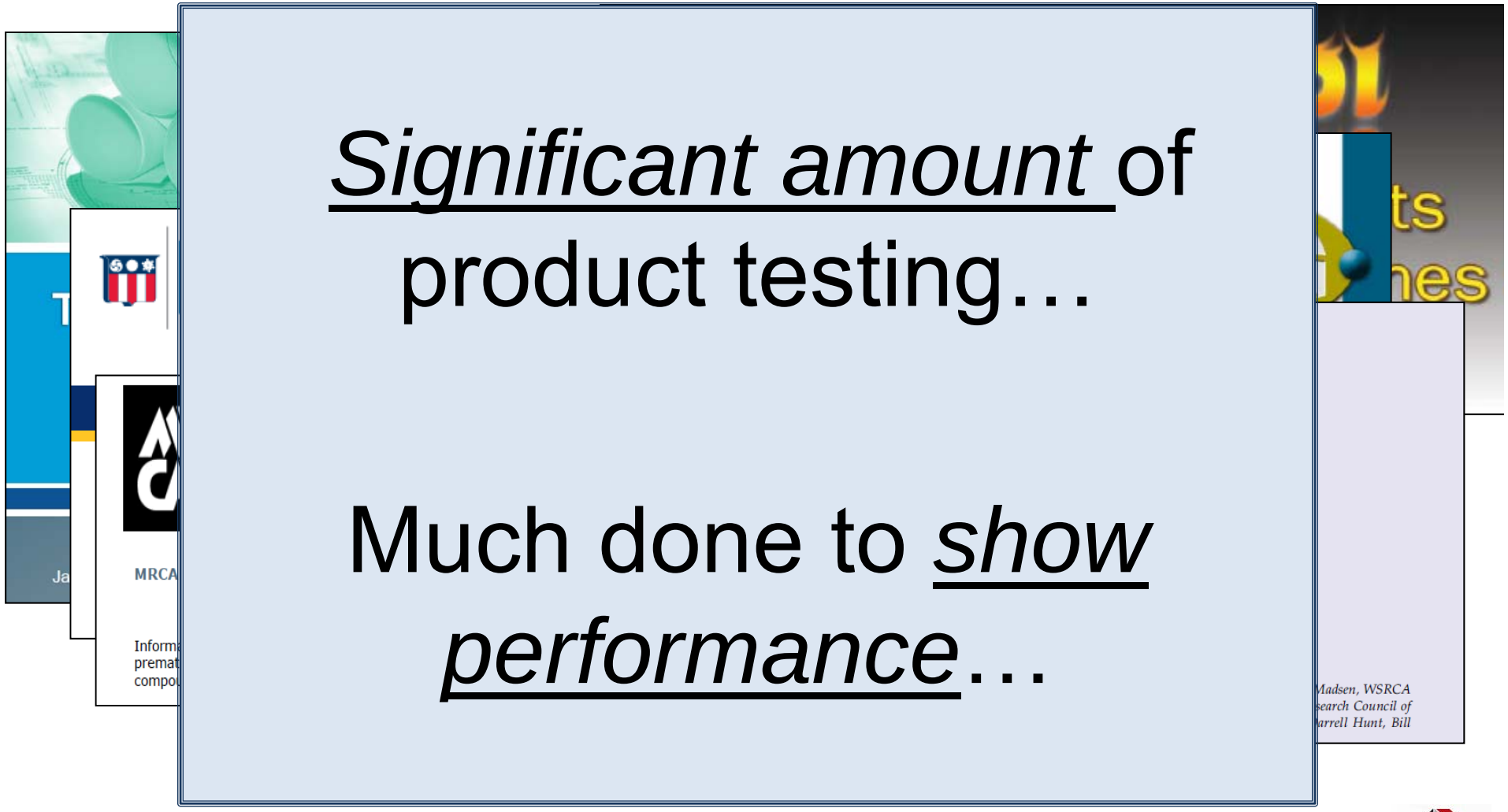
In Fact, Over the Past 8 Years…

> 20 Presentations & Papers/Articles About TPO Membranes

Many, You Might Recall…



Something All of These Papers/Articles Have in Common…



Significant amount of product testing…

Much done to *show performance*…

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Heat Aging

Used in evaluating product formulation

The higher the temperature, the faster you get an answer (weeks not months!)

ASTM calls out for testing at 240F

8-10 years ago, mfrs started testing at higher temperatures

Even Drawing Conclusions About Longevity
Based on Oven Aging…

Product (and thickness)	Oven Aging				200°F Field Exposure Predicted Years (assuming 6 hrs/day @ 200°F)
	280°F	240°F	240°F	200°F	
	Actual Days to Cracking		Predicted Days to Cracking		
	(X)				
A. 45 mil	20			941	10
B. 45 mil	28			1017	11
C. 60 mil	31			941	10
D. 80 mil	34	212	255	941	10
E. 60 mil	37	296	268	1314	14
F. 80 mil	40	296	281	1314	14
G. 80 mil	48	344	315	1527	17
H. 80 mil	68	399	400	1772	19
I. 60 mil	76	399	434	1772	19
J. 80 mil	80	475	452	2109	23

Predicted Years
(assuming 6 hrs/day @ 200°F)

Confused About WHAT Temperature?

Is there a difference in results between testing at 240F or 275F?

2014 ASTM Inter-Laboratory Study to evaluate ***IF*** there is a difference…

"It appears that the use of 275F as a new nominal temperature is very appropriate"

ASTM ILS…What does it mean?

In other words…relative performance between products/ formulations tested at 240F or 275F is the same…

It's just that testing at 240F will take longer

(6 months at 275F…>30 months at 240F!)

Yet…Maybe You've Been Right

- Internal testing/ Single attribute testing
- Used old competitive material
- Data presented out of context
- Didn't always show all samples
- Cherry picked your own material
- Not using the right measurement

Yet…Maybe You've Been Right

Internal testing/ Single attribute testing

Used old com

Data presented without context

Not using the right measurement

There's Been NO Independent 3rd Party Testing With Rigorous Sampling!

Recognized a Need…

Plan	Collect	Test
In 2013, GAF retained SRI	**SRI to independently obtain material**	**5 rolls from each TPO plant** **Target 2013 production dates** **Testing *beyond* D6878**

The Program…
Sampling, Testing, & Results

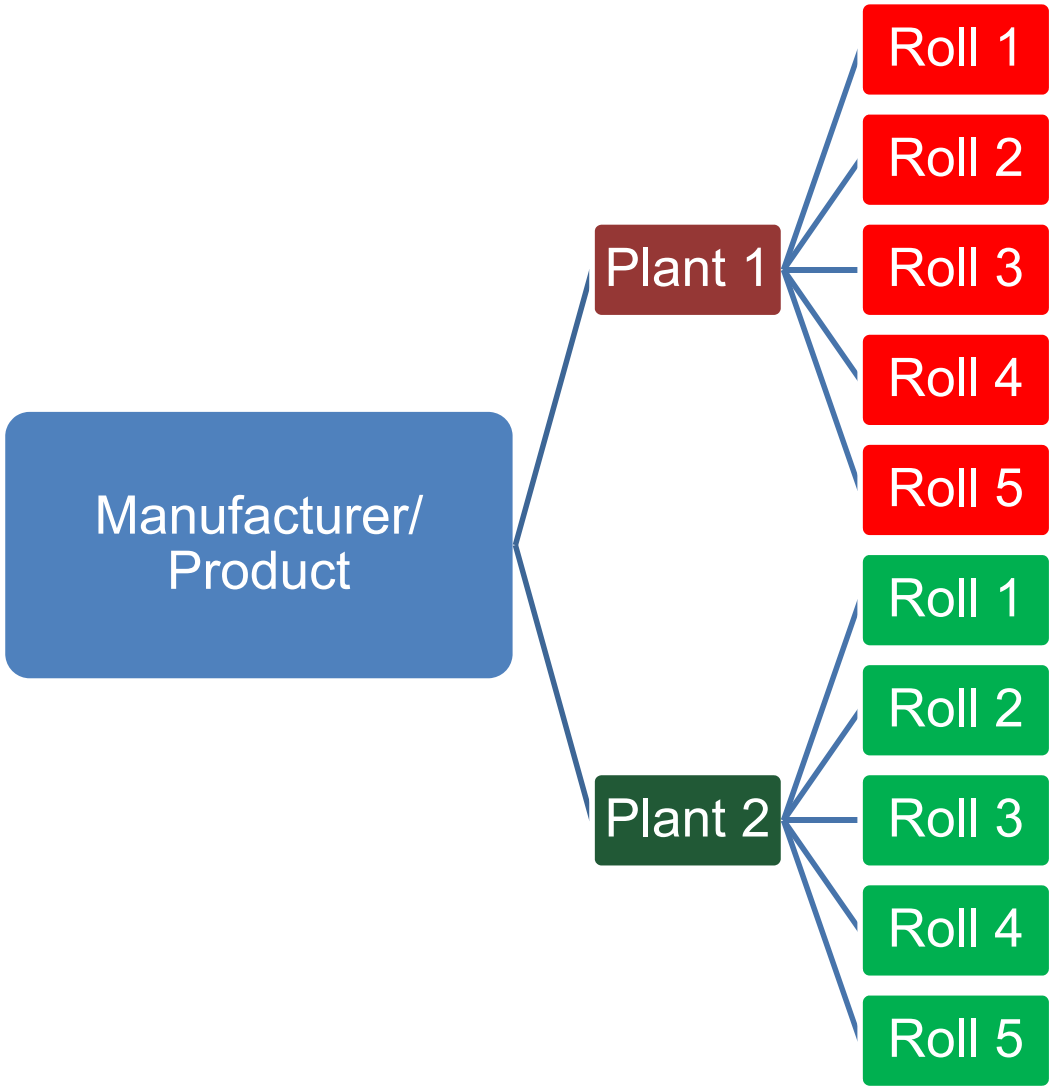
TPO Study Sampling Plan

- Obtain rolls with different 2013 manufacturing dates for each
- Obtain 5 rolls per plant if possible for each manufacturer
- Purchase full roll 10’ x 100’, ship 10’ length to SRI with original roll wrapper and tag
- Obtain rolls directly from the market or distribution

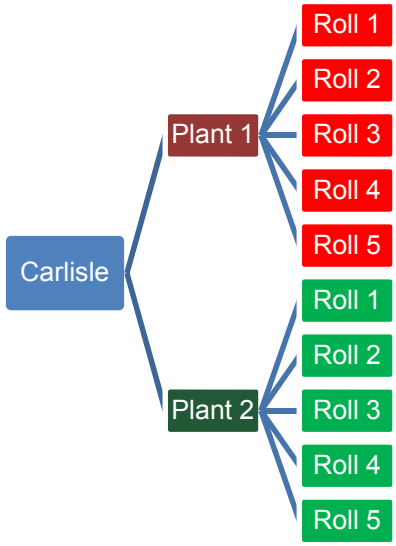
TPO Manufacturers/Products Sampled - White 60 mil except as noted

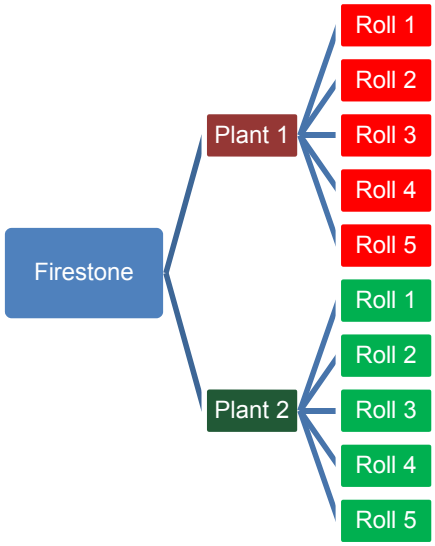
- Carlisle
- Firestone
- GAF
- GAF Extreme – 50 mil
- GAF Extreme
- JM

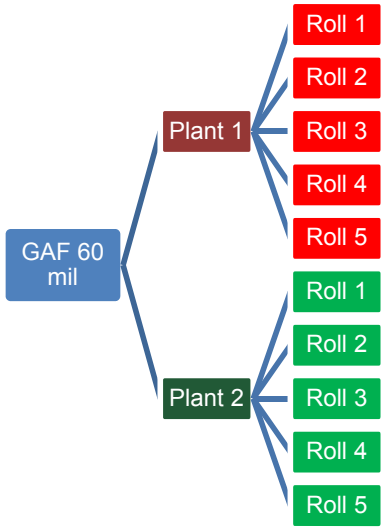
What We're Talking About…

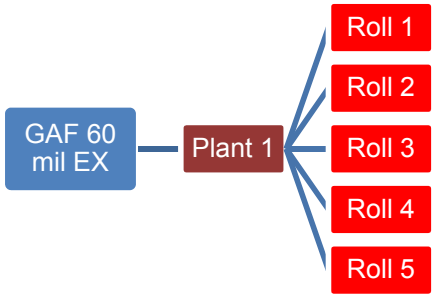


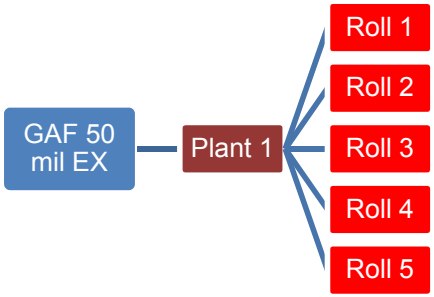
What We're Talking About… In Context

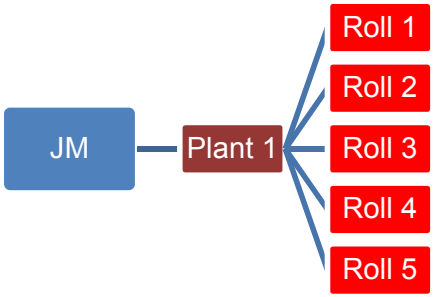








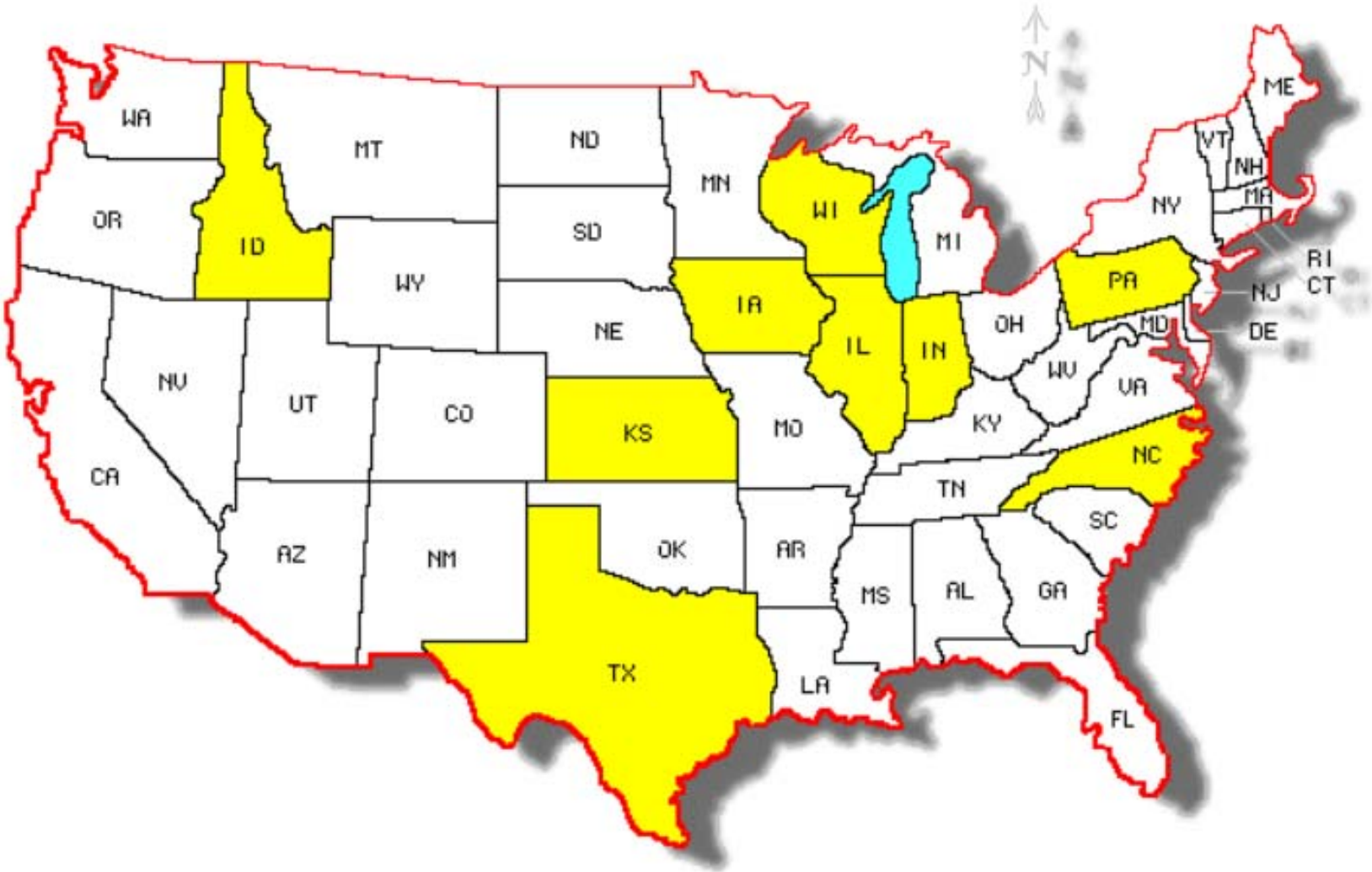




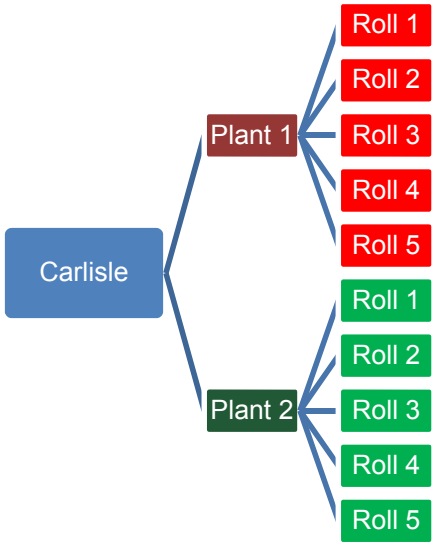
TPO Sampling Data

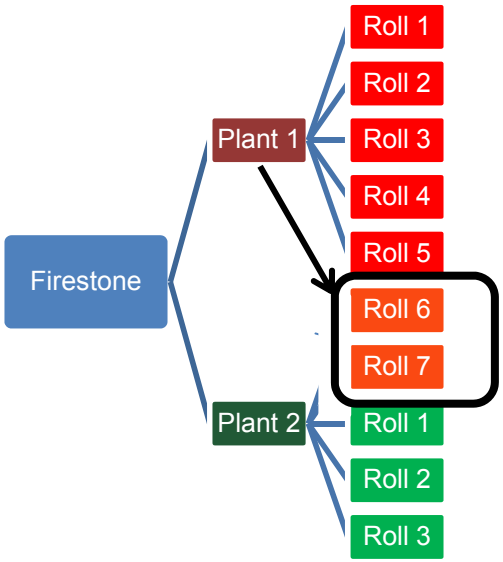
- Carlisle – 10 Rolls dated from Jan – Dec 2013
- Firestone – 10 Rolls dated from May – Nov 2013
- GAF – 8 Rolls dated from May – Dec 2013;
  2 Rolls Jan 2014
- GAF 050 Extreme – 5 Rolls dated from Jan – Dec 2013
- GAF 060 Extreme – 5 Rolls dated from Jan – Dec 2013
- JM – 5 Rolls dated from Jan – Nov 2013

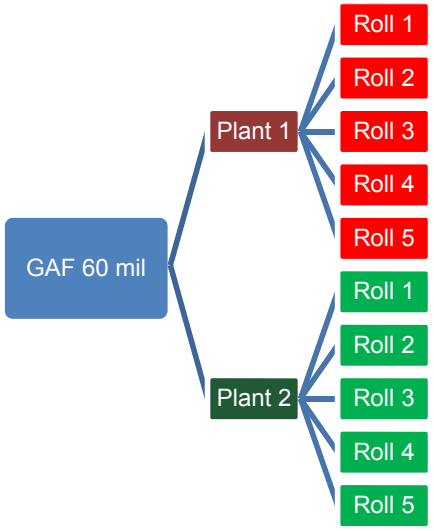
TPO Roll Sample Source Areas - 2013

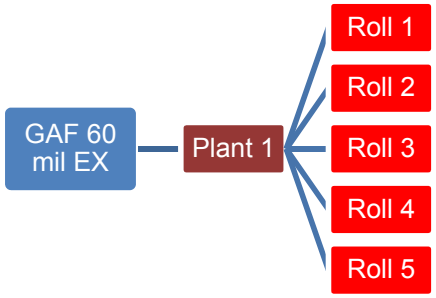


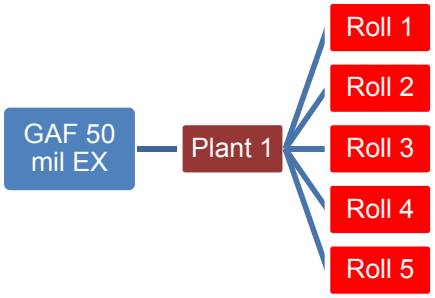
Where We Ended UP…45 Rolls!

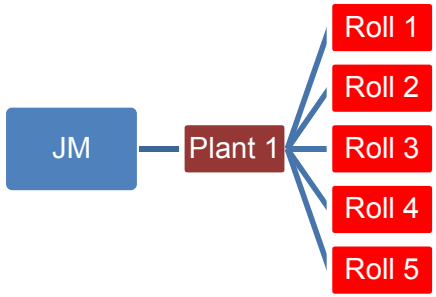












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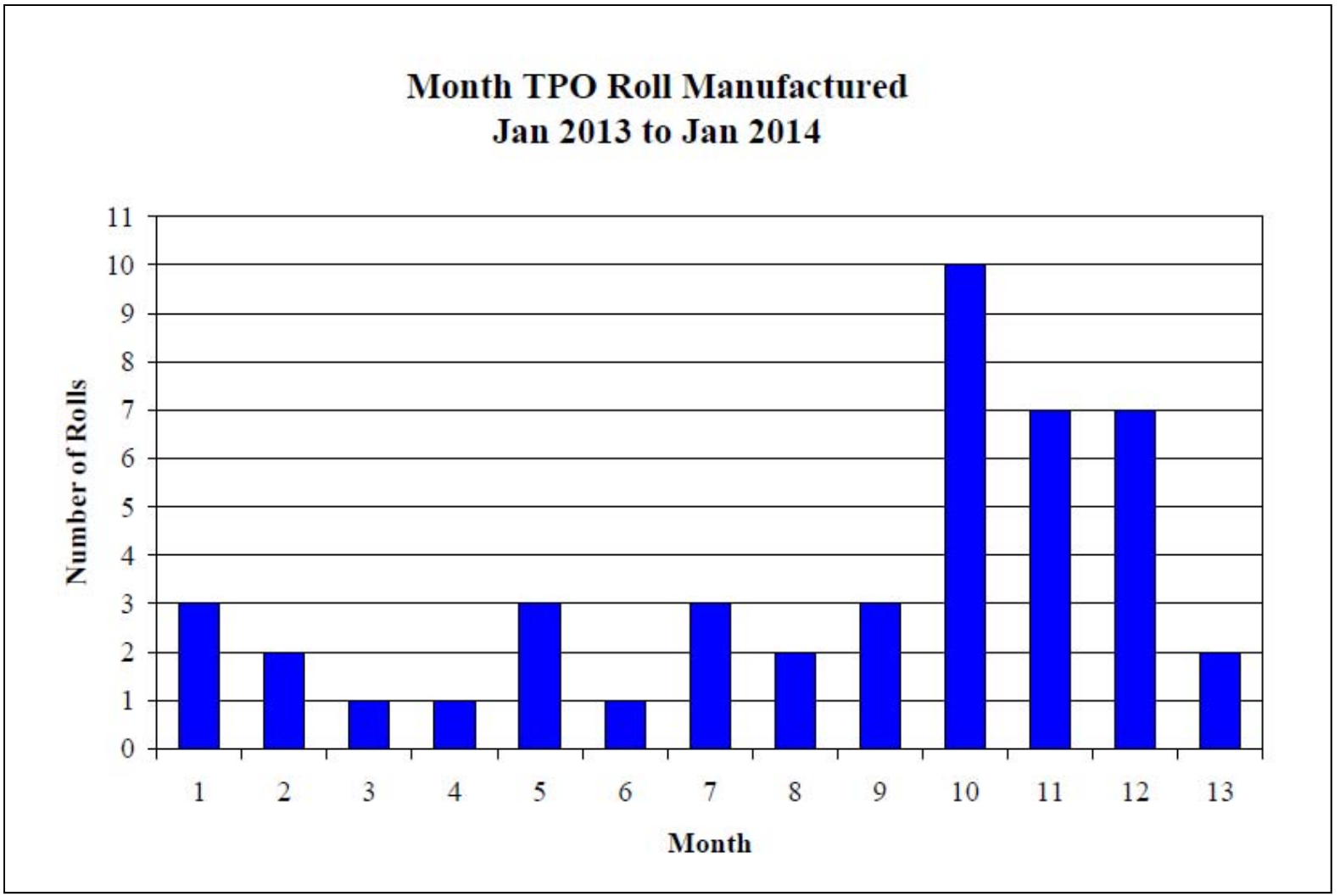
45 Rolls… Manufactured over 13 Months

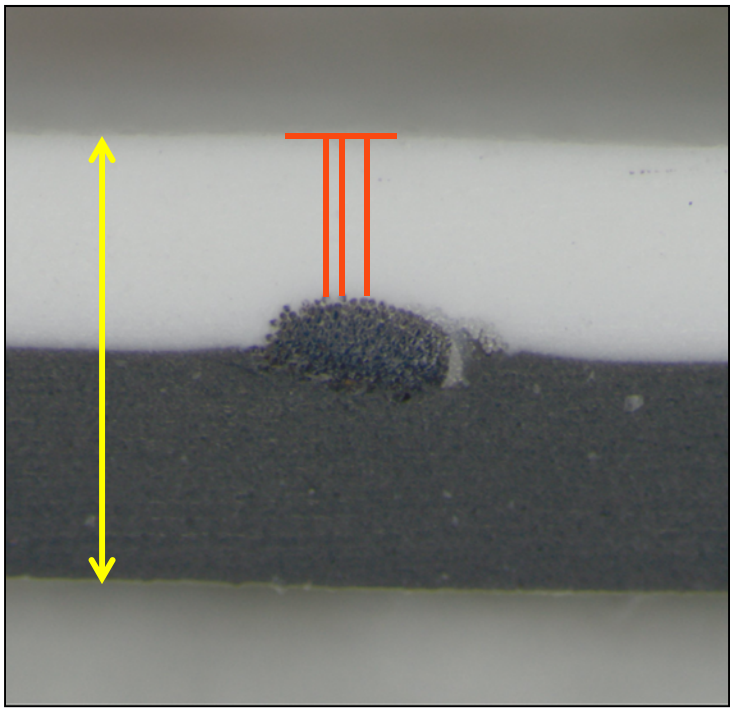


Test Methods

Thickness

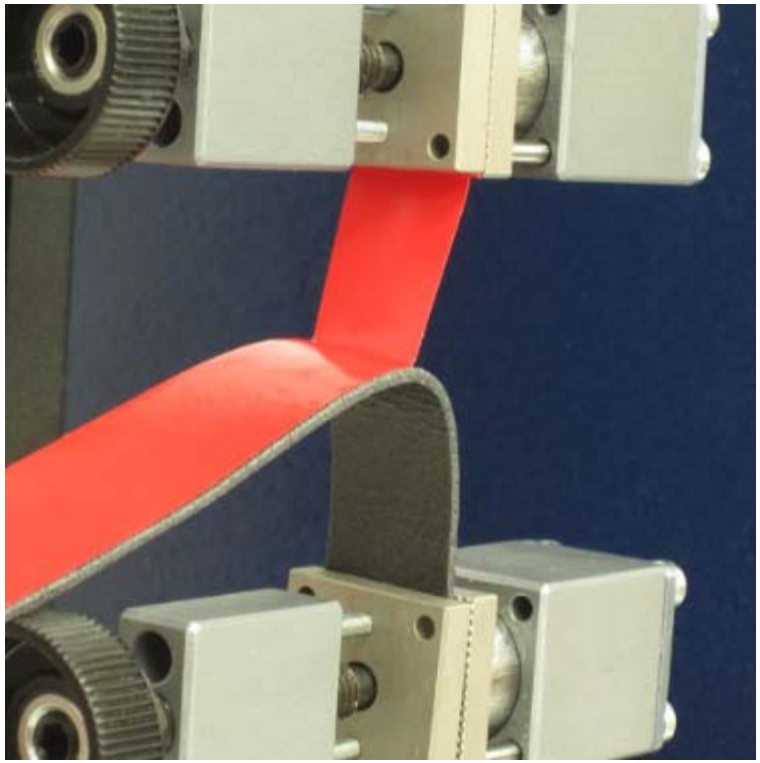
- Overall Sheet ASTM D751
- Thickness of Coating ASTM D7635

  Over Scrim



Lamination Strength

- ASTM D1876 **Standard Test Method for Peel Resistance of Adhesives (T-Peel Test)**



Heat Aging

- ASTM D573
  - 275F (135C)
  - Measured weight change to 0.001 gram accuracy during heat aging of 2”x6” samples
  - Cracks were checked by mandrel bend over a 3” diameter solid round section @ 7x magnification
  - Days to cracking were monitored concurrent with weight change

Of note: samples underwent bending from 5 – 40 times!

Accelerated Weathering

- ASTM G154
  - QUV with UVA 340 lamps
  - 700 minute light cycle followed by 20 minutes of water spray (12 hour total cycle)
  - Exposure was 30,240 kJ/(m^2·nm)

But Wait!
We Weren't Done yet…

One Final Test…

Accelerated Weathering

- ASTM G154
  - QUV with UVA 340 lamps
  - 700 minute light cycle followed by 20 minutes of water spray (12 hour total cycle)
  - Exposure was 30,240 kJ/(m^2·nm)

226 Days…
3X Current
ASTM
Requirements

Heat Aging

- ASTM D573
  - 275F (135C)
  - Measured weight change to 0.001 gram accuracy during heat aging of 2"x6" samples
  - Cracks were checked by mandrel bend over a 3" diameter solid round section @ 7x magnification
  - Days to cracking were monitored concurrent with weight change

Results

Overall Sheet Thickness –
Location Key
(where we measured 6 times across the width of the sheet)

		Measurment Location Key					
		Exposed Edge					Lap Guide Edge
Reading locations, in	Width, ft	A	B	C	D	E	F
inches, measured	5	1	13	25	37	49	59
from exposed edge	6	1	15½	30	44½	59	71
(A & F locations both	8	1	20	39	58	77	95
1-inch from edge)	10	1	24	48	72	96	119

*This same location key was used for thickness over scrim

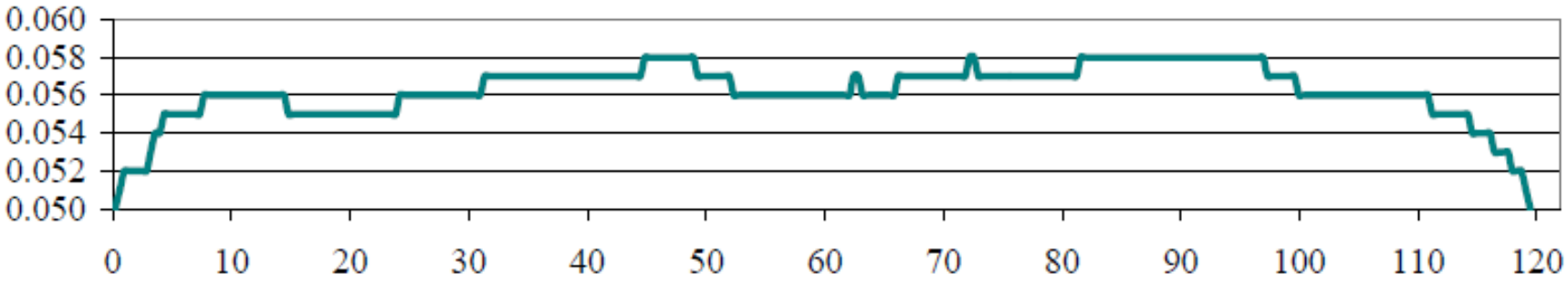
.

Overall Sheet Thickness

- 060 TPO the average thickness of each product was 55-57 mils
- The greatest difference between the average thickness of rolls from the same manufacturer was 3 mils
- In addition, approximately 12,000 total individual measurements taken across the width of the 45 sample rolls to create a thickness profile of each roll

Overall Sheet Thickness Profile

TPO Product #4

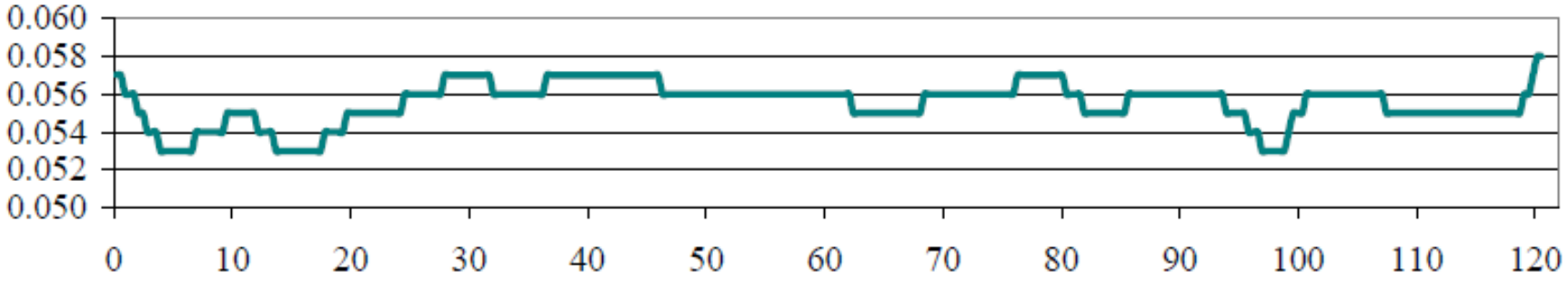


Average value, in	0.056
Minimum reading, in	0.050
Maximum reading, in	0.058
Number of Readings	319
Gauge deadweight, oz	6
Gauge pressure foot Ø, in	0.375

8 mil range

Overall Sheet Thickness Profile

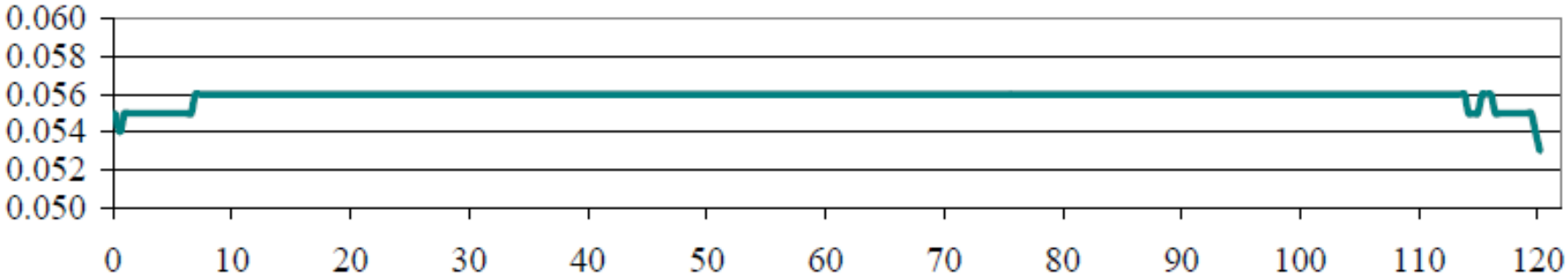
TPO Product #6



Average value, in	0.056
Minimum reading, in	0.053
Maximum reading, in	0.058
Number of Readings	322
Gauge deadweight, oz	6
Gauge pressure foot Ø, in	0.375

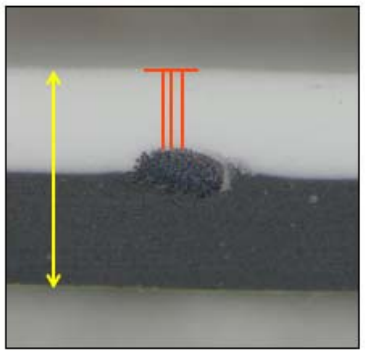
Overall Sheet Thickness Profile

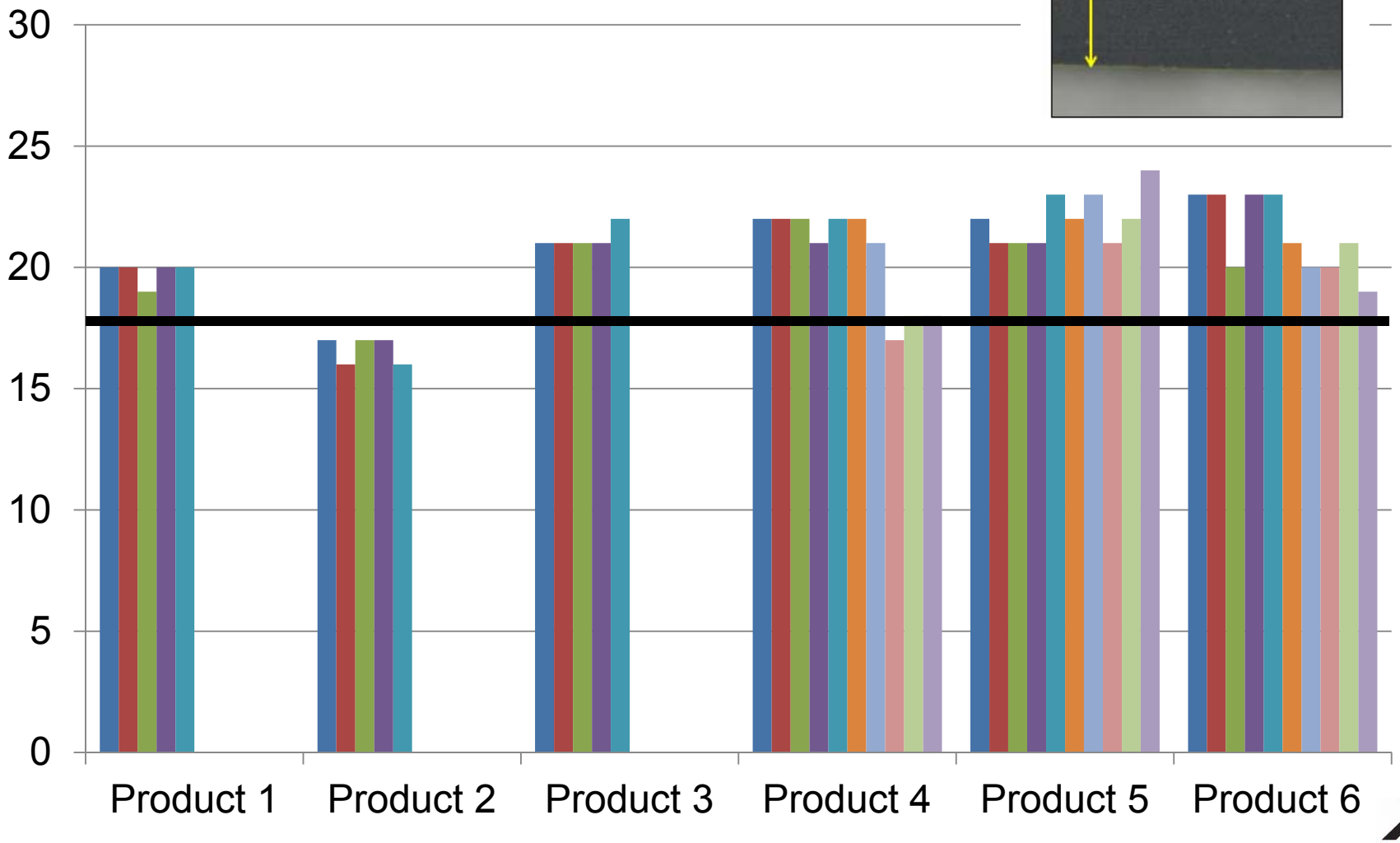
TPO Product #5



Average value, in	0.056
Minimum reading, in	0.053
Maximum reading, in	0.056
Number of Readings	321
Gauge deadweight, oz	6
Gauge pressure foot Ø, in	0.375

Thickness Over Scrim





Laminate Strength @ Exposed Edge

- 1 roll randomly selected from each plant, all measurements showed film-tearing bond
- Minimum of all T-Peels = 29.3 lbf/in
- Maximum of all T-Peels = 51.3 lbf/in
- Average of all 9 rolls = 40 lbf/in

Heat Aging

- 6 products spread over 45 rolls
- Current standard…< 1% mass loss
- Current lab practice is “failure” is defined as cracking at 7x magnification when bent

What this program shows…

- variation in amount of weight loss between manufacturers
- significant differences in total time to failure between manufacturers
- stark differences between the “tightness of the data”

Why We Look At Cracking

Test Sample

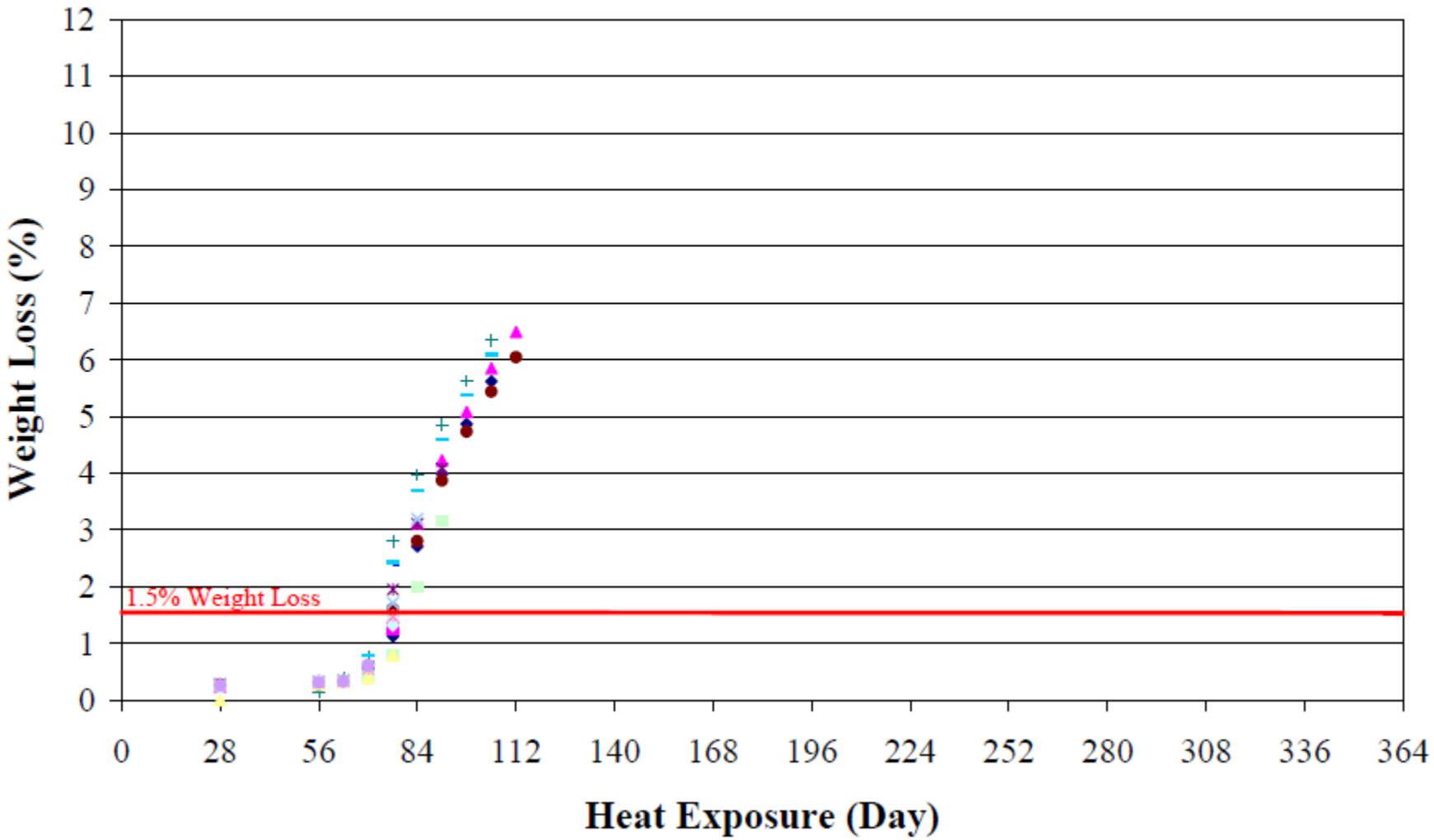
Real World

Weight Loss vs. Cracking As a Failure Mode

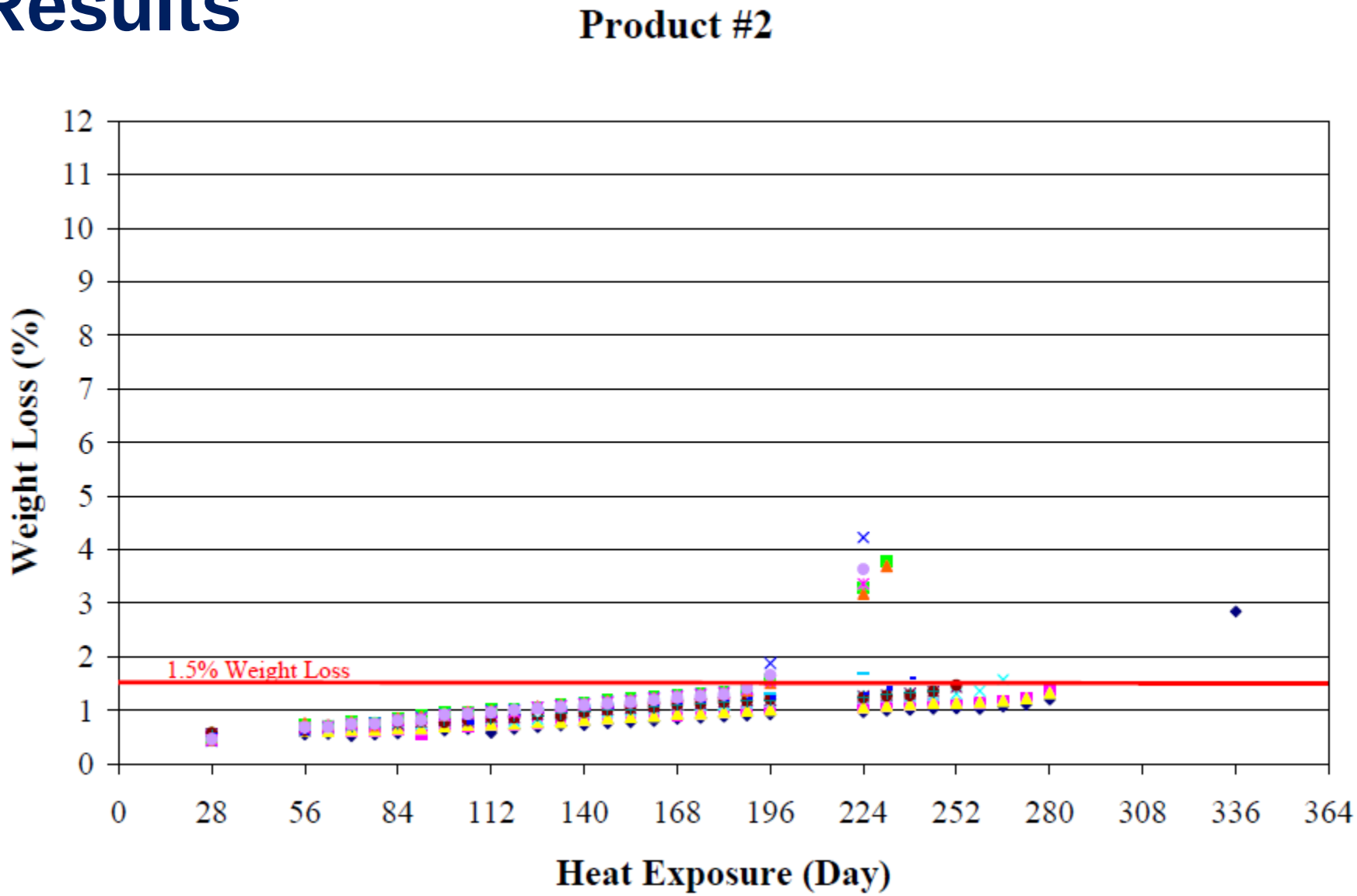
Product that cracked at less than 1.5% weight loss

Product with excessive weight loss

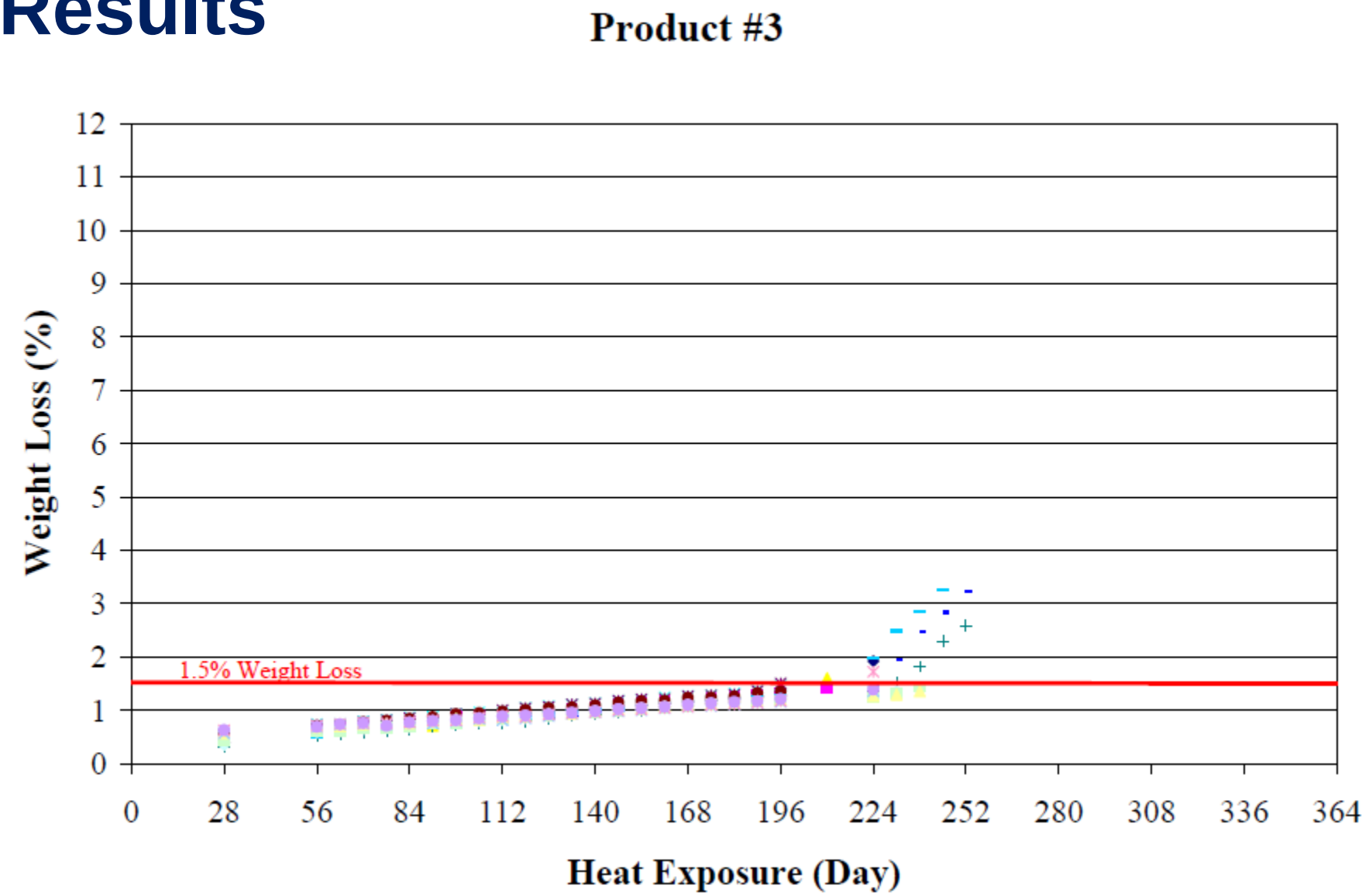
Results


Product #1
Weight Loss (%)
12
11
10
9
8
7
6
5
4
3
2
1
0
1.5% Weight Loss
0
28
56
84
112
140
168
196
224
252
280
308
336
364
Heat Exposure (Day)

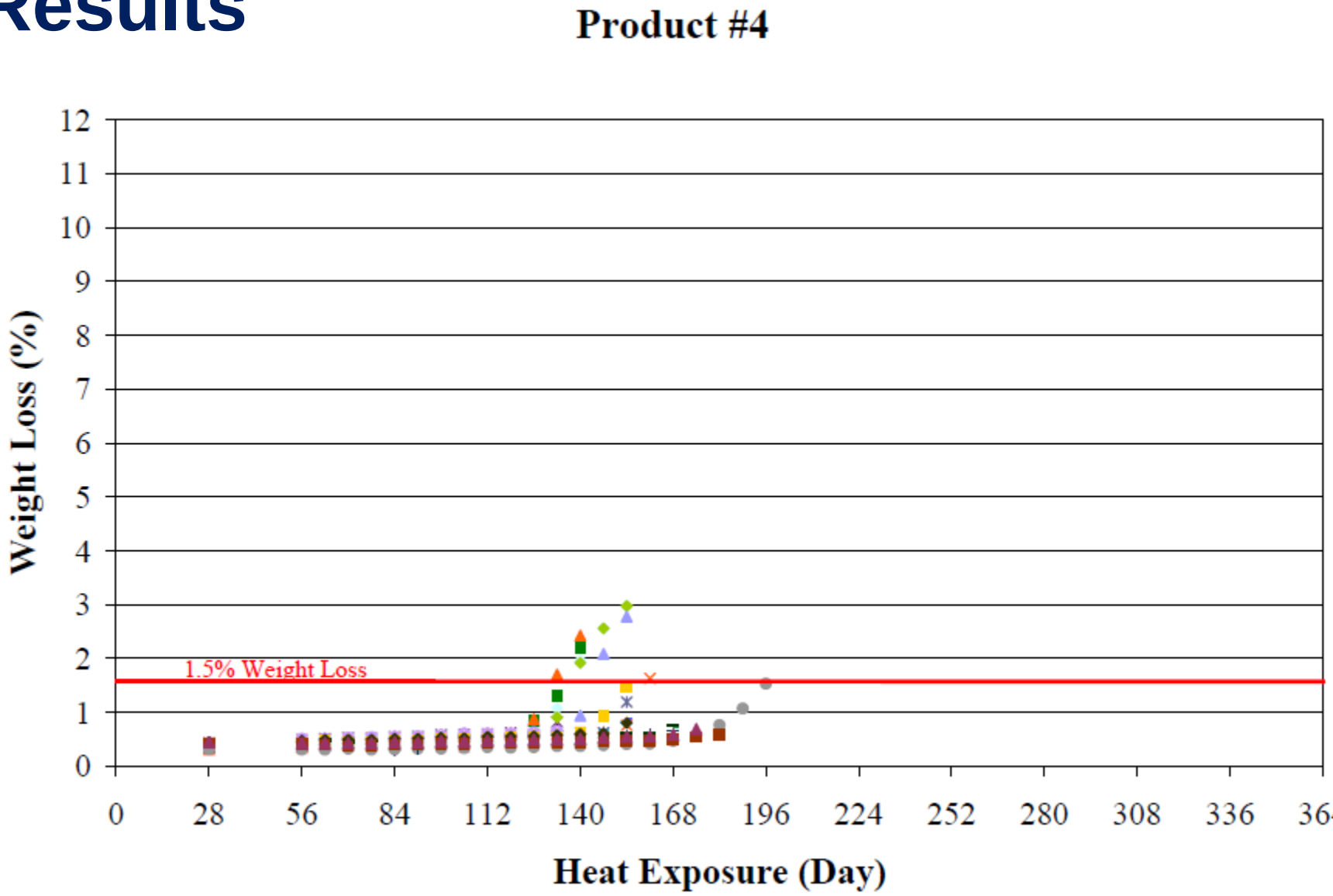
Results


Product #2
Weight Loss (%)
12
11
10
9
8
7
6
5
4
3
2
1
0
1.5% Weight Loss
0
28
56
84
112
140
168
196
224
252
280
308
336
364
Heat Exposure (Day)

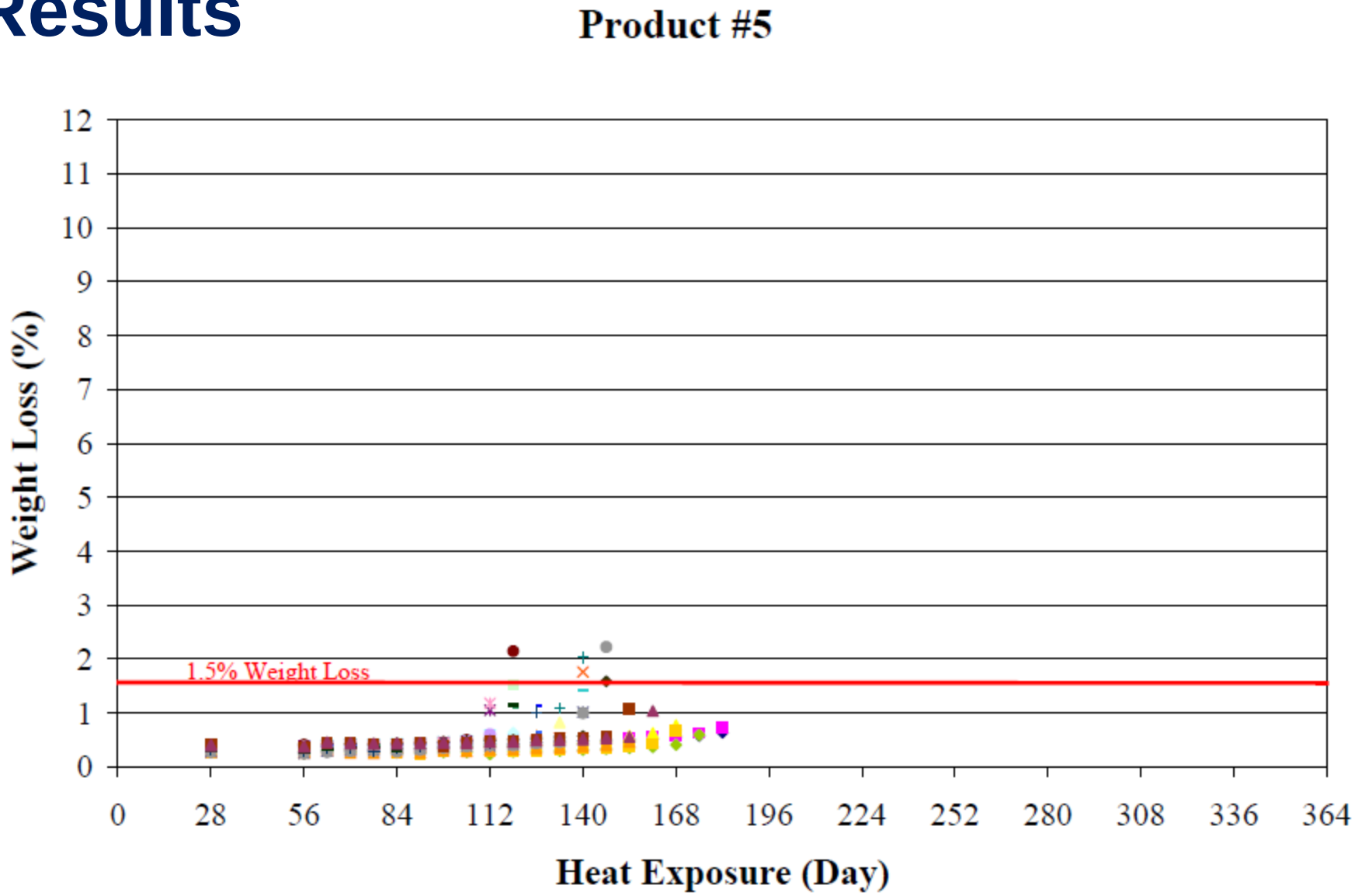
Results


Product #3
Weight Loss (%)
12
11
10
9
8
7
6
5
4
3
2
1
0
1.5% Weight Loss
0
28
56
84
112
140
168
196
224
252
280
308
336
364
Heat Exposure (Day)

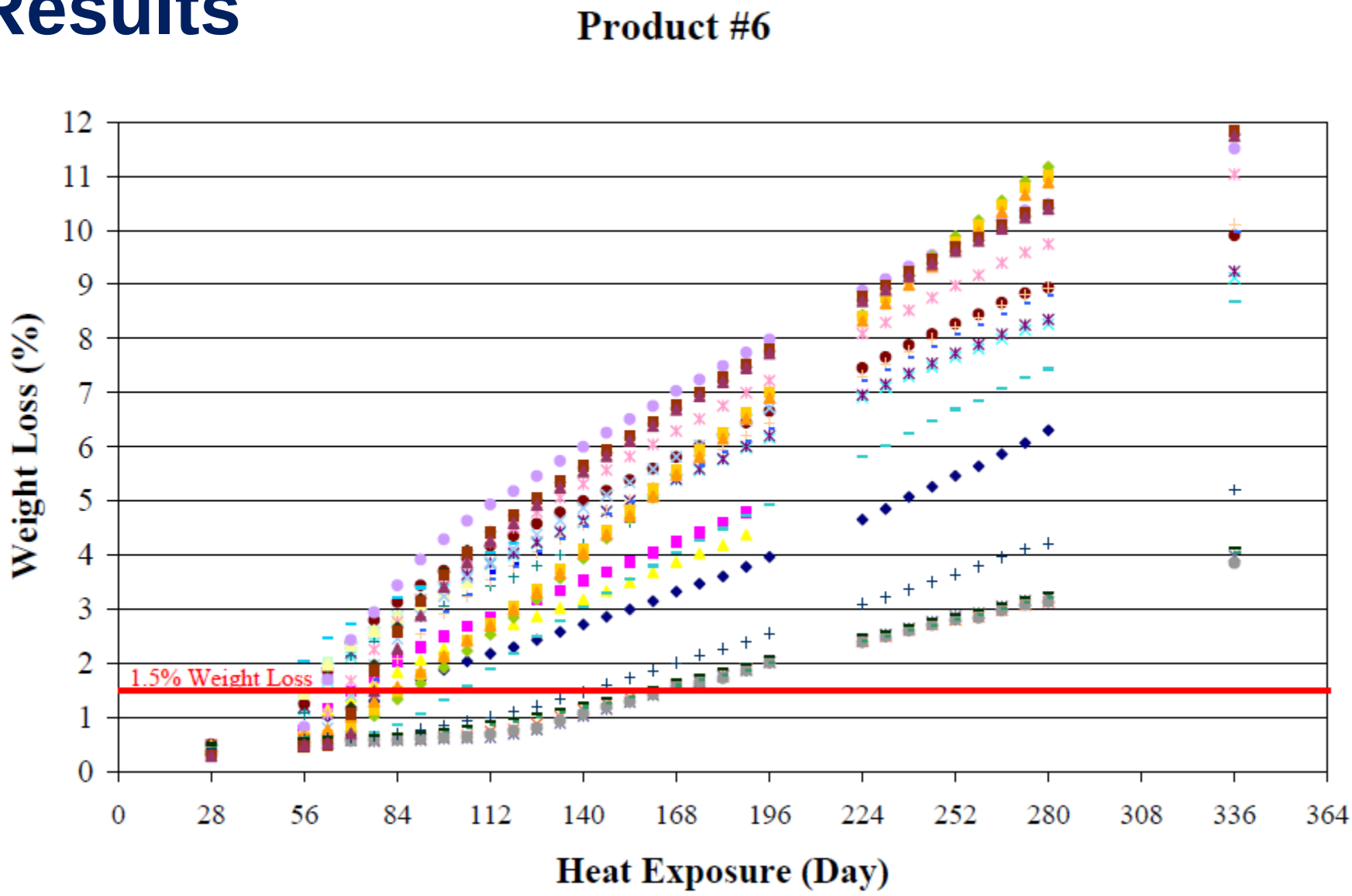
Results


Product #4
Weight Loss (%)
12
11
10
9
8
7
6
5
4
3
2
1
0
1.5% Weight Loss
0
28
56
84
112
140
168
196
224
252
280
308
336
364
Heat Exposure (Day)

Results


Product #5
Weight Loss (%)
12
11
10
9
8
7
6
5
4
3
2
1
0
1.5% Weight Loss
0
28
56
84
112
140
168
196
224
252
280
308
336
364
Heat Exposure (Day)

Results


Product #6
Weight Loss (%)
0
1
2
3
4
5
6
7
8
9
10
11
12
1.5% Weight Loss
0
28
56
84
112
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168
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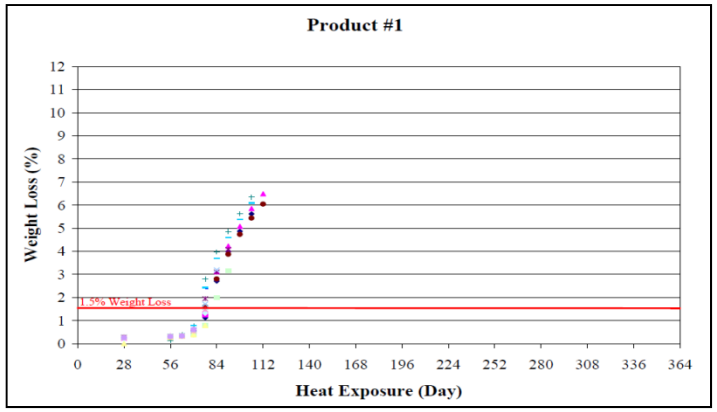
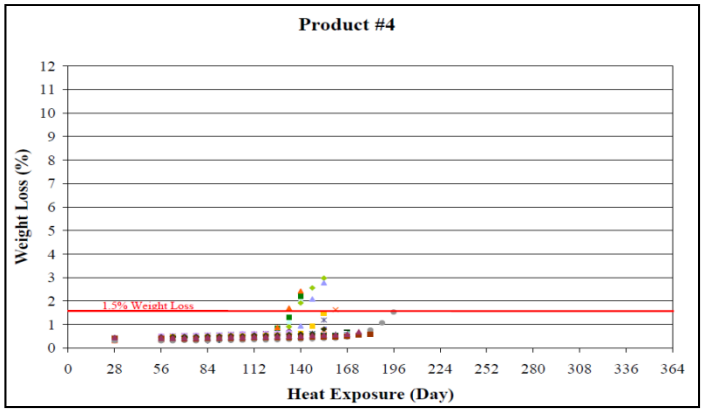
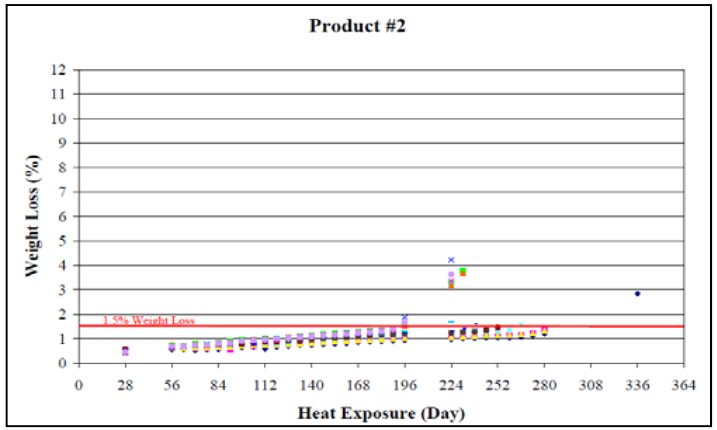
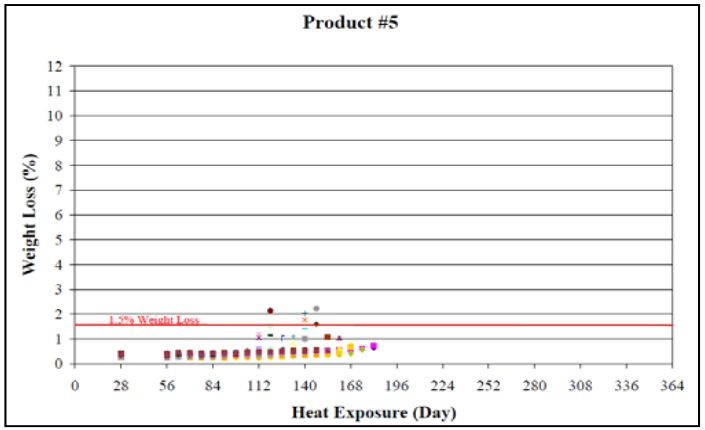
336
364
Heat Exposure (Day)

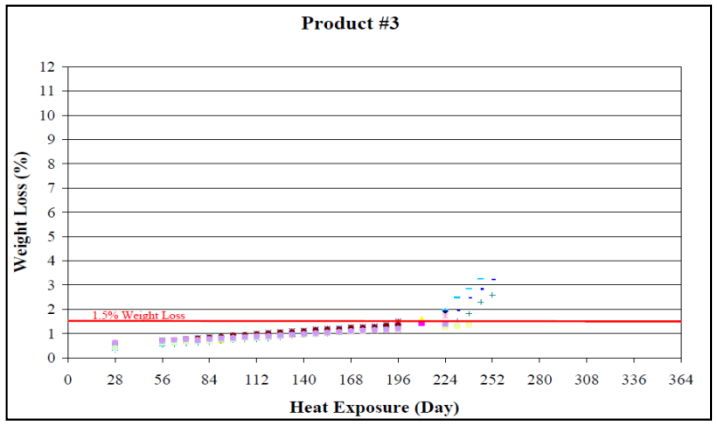
Heat Aging Composite View

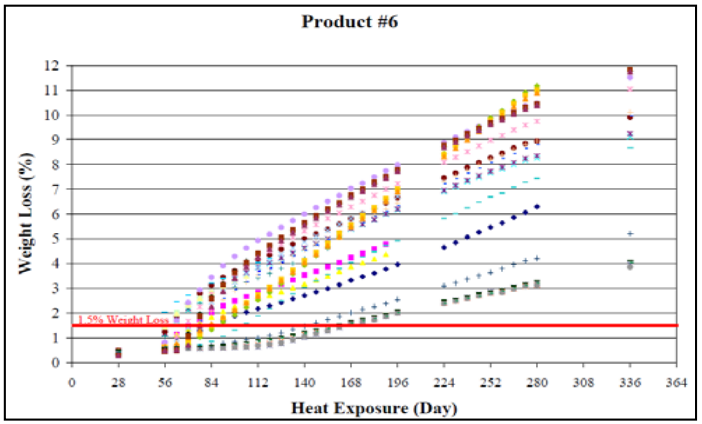












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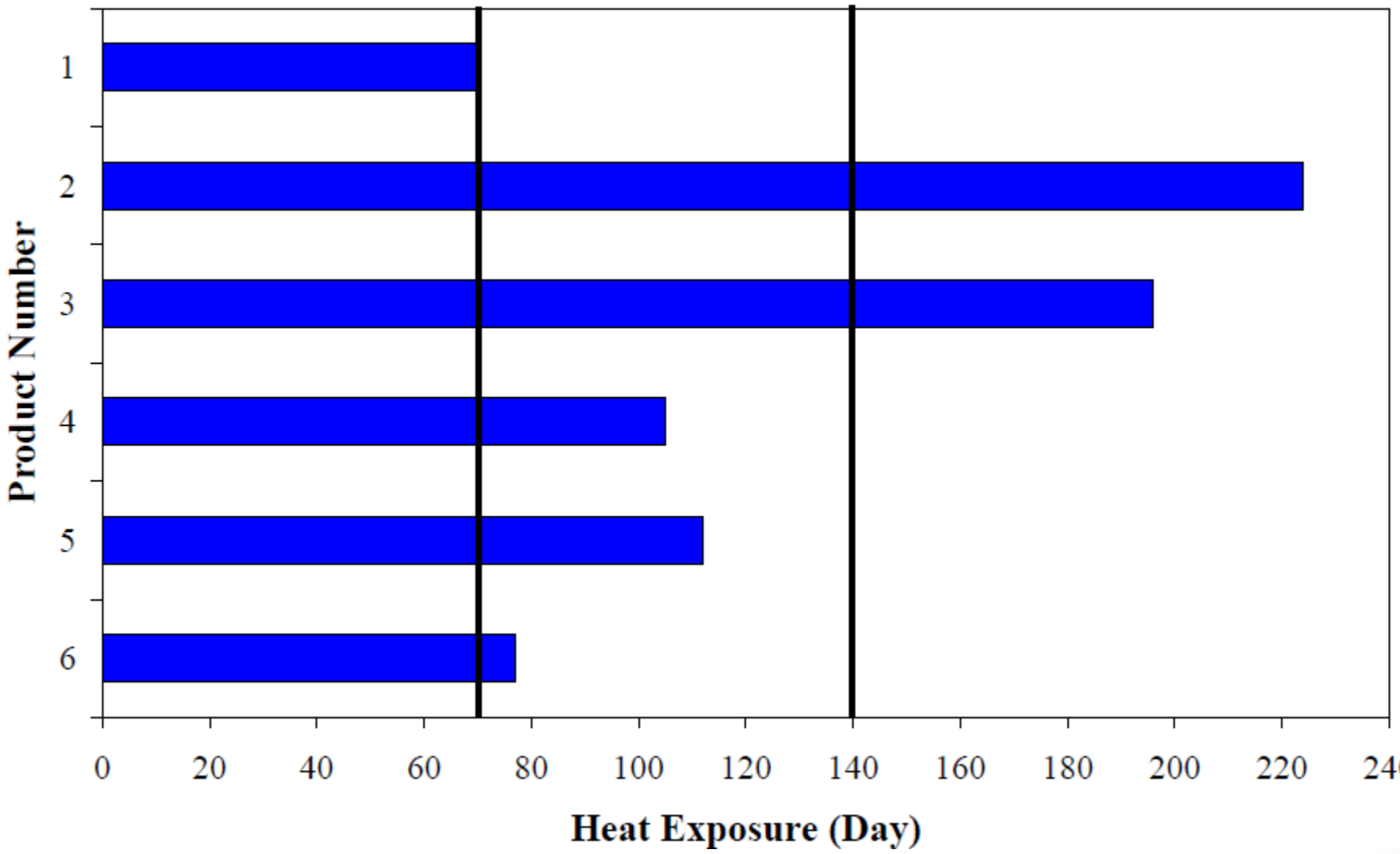
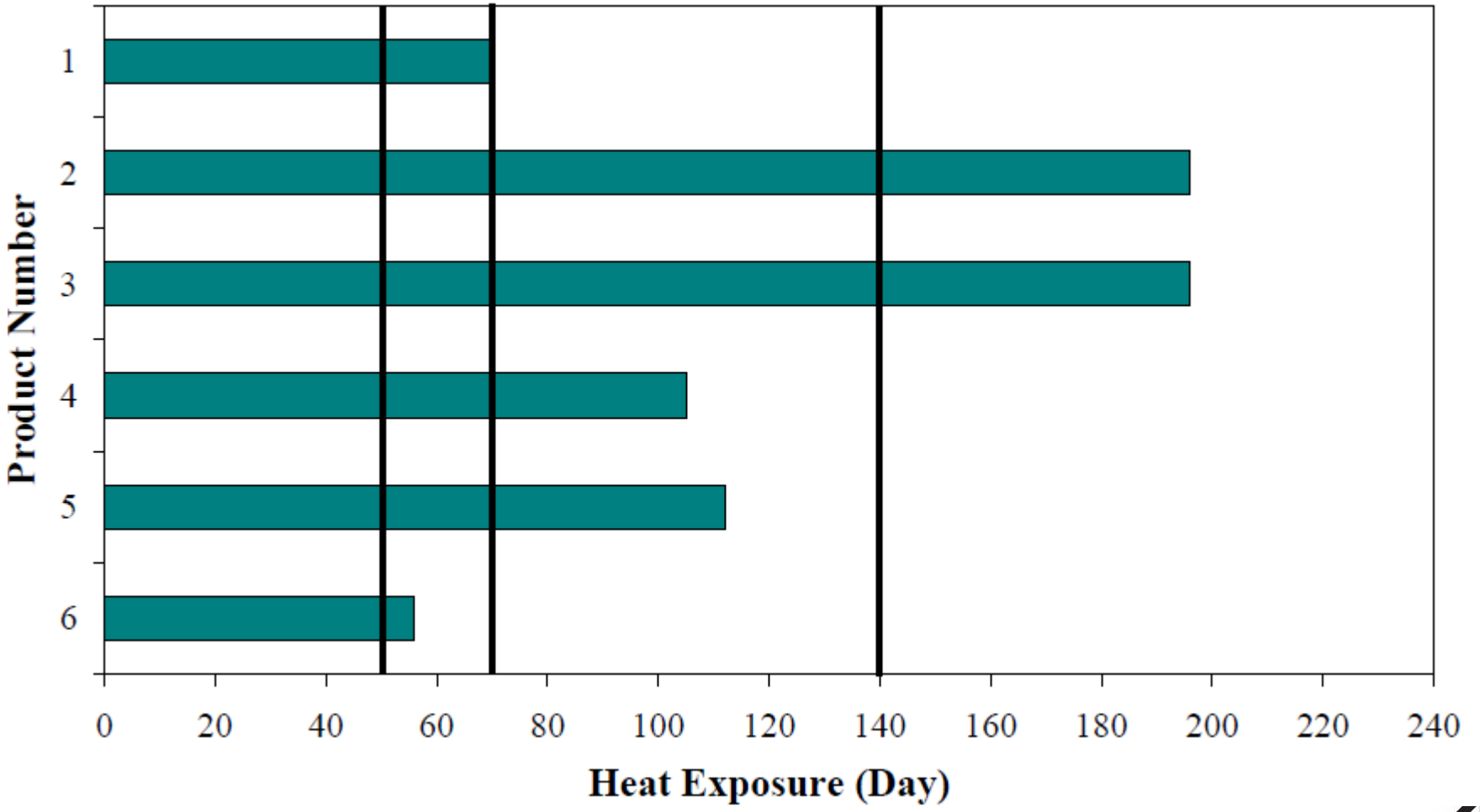
Heat Aging - Days to First Crack



Heat Aging - Days to Either First Crack or >1.5% Wt. Loss

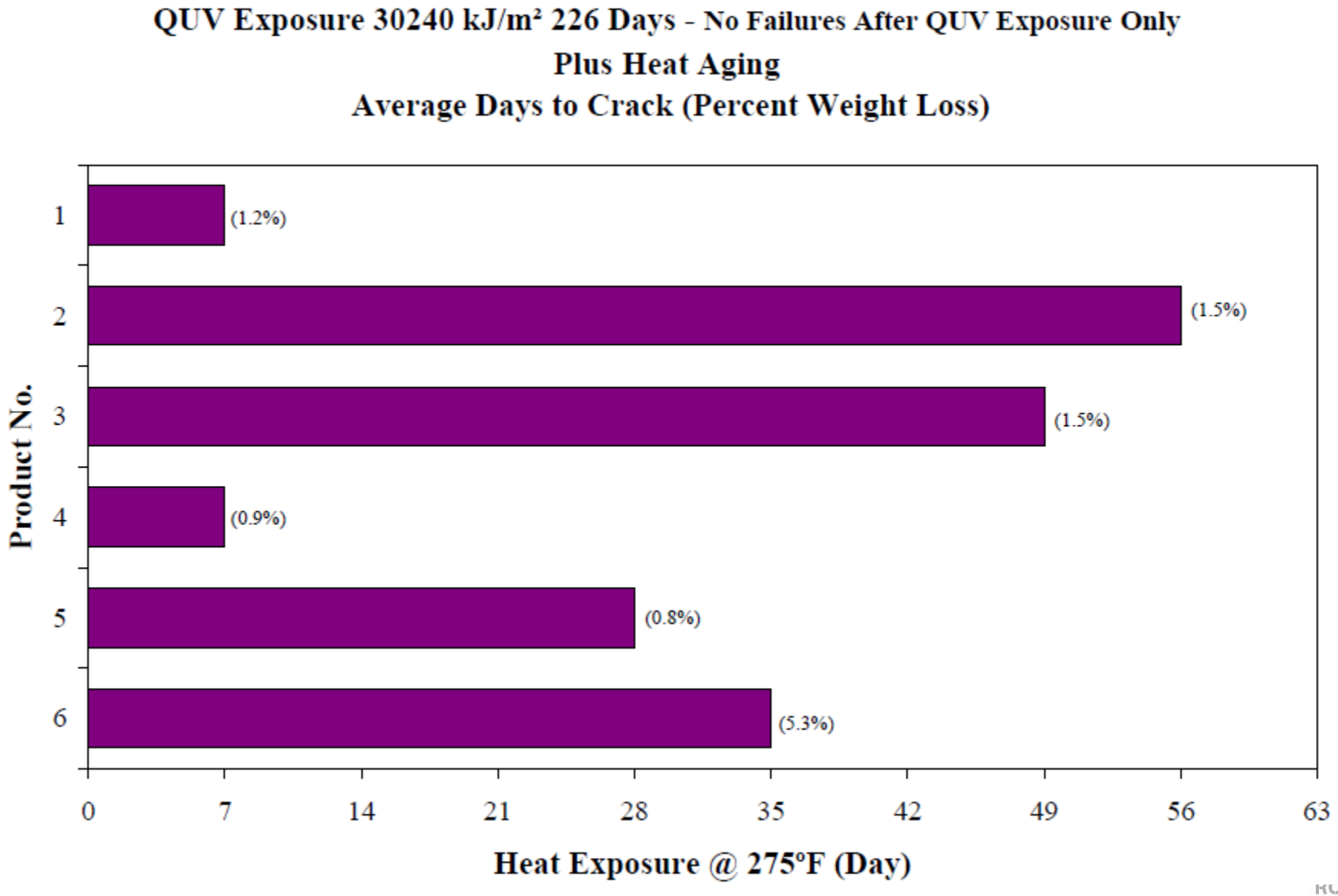


Accelerated Weathering

- ASTM G154
  - QUV with UVA 340 lamps
  - 700 minute light cycle followed by 20 minutes of water spray (12 hour total cycle)
  - Exposure was 30,240 kJ/(m^2·nm)

No failures after 3x ASTM requirements for any product

QUV + Heat Aging



Conclusions…
Pulling it All Together

Take Aways

- TPO as a Product Class
- Product Quality
- Product Durability
- Suggestions for Raising the Standard

TPO As a Product Class

- There has been significant and notable improvements in product formulations over the past 10 years

- These improvements have been made to raise the performance of these products in service, especially temperature loading

Product Quality

- This testing took *multiple measurements from multiple rolls…and* in general, the results show notable consistency, both within roll and between rolls

- *Even with manufacturing dates that generally spanned over a full year*, there were many products that showed consistency in results – which indicates process control in manufacturing and confidence in formulation

Product Durability

- Today's TPO membranes have evolved
- QUV + Heat Aging – shows a level of product durability not seen 10 years ago (consider heat aging failures at 28 – 45 days without QUV 10 years ago)
- There are formulations available that approach 300 days of heat aging with minimal weight loss
- This body of work may contribute to the correlations between heat aging, UV resistance and predicted service life

Considering ASTM…

Suggestions for Raising the Standard

- At a minimum…2 Grades Based on Heat Aging – Failure Mode Cracking

Grade	Heat Aging Days to Cracking, Minimum
1	70
2	140

Suggestions for Raising the Standard

- The data suggests a strong relationship between cracking and 1.5% weight loss

- Given this relationship, the case can be made for 3 Grades

Grade	Heat Aging Days to Cracking, Minimum With <1.5% Weight Loss
1	50
2	70
3	140

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Thank You!

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