Water Vapor Uptake and Release in Printed Boards

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Abstract:
Excessive moisture entrapped/absorbed within printed board laminates can expand during soldering operations, causing delamination or other damage. While moisture absorption data is available for some materials used in PB construction, little information has been made available for finished PBs, where not only the laminate material is important in moisture gain or loss, but also the board thickness, copper content, details of the construction, and assembly process conditions. This study measures moisture absorption and desorption rates within various representative rigid multilayer PB structures, under varying conditions of temperature and humidity, including shop ambient environments and baking operations. Weight gain or loss attributable to moisture was measured using an analytical balance. The effectiveness and response times of humidity indicator cards used in PB packaging was also assessed. This information may be used to develop process controls for PB fabrication or PB assembly operations, dry storage practices, or baking procedures.

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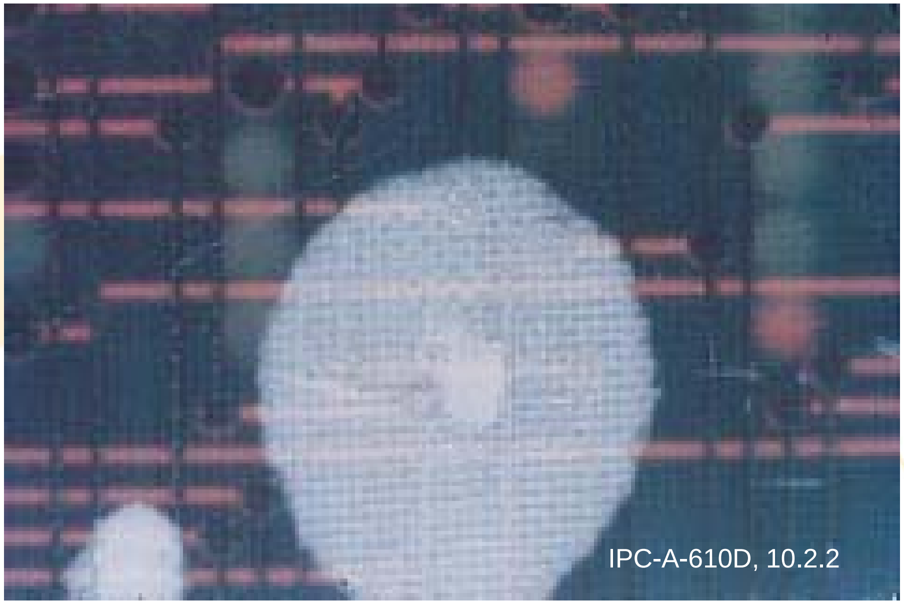
Introduction - What We Know

- PBs can be damaged by soldering heat, especially at lead-free soldering temperatures



- Baking before soldering prevents damage

What We Know (Cont’d)

- PB laminates readily absorb moisture from the air
- Moisture is absorbed at the surface, and penetrates deeper over time to saturate the interior
- Vapor pressure inside the laminate increases during soldering, which may cause cracking, delamination, or other damage
- Moisture can be absorbed at any point in the process, during fabrication, transport, storage, or assembly
- Baking removes moisture, but adds cost and cycle time, and can compromise solderability
- IPC-1601 (in development) will provide guidance for process controls and dry storage, BUT
- Rates of moisture uptake and release may vary depending on the design of the PB and environmental conditions during exposure

What We Know (Cont'd)

- Because of concerns with moisture sensitive components, we've learned some things about diffusion (ref. Fick's Law, J-STD-020)
- Laminate manufacturers may have some data:
  - Moisture absorption characteristics of laminates
  - Maximum acceptable moisture content for soldering
- BUT laminate data may not apply to the finished PB level
  - Boards gain/lose moisture slower than the bare laminate
  - Moisture may not be distributed equally depending on depth from the surface, and presence of copper
- A moisture sensitivity classification scheme like J-STD-020 may not be practical

What We Need To Know

- How much moisture does a PB absorb with time under varying conditions of ambient temperature and humidity?
- Aside from the choice of laminate, what are the effects of design aspects like PB thickness, and distribution of Cu?
- Is moisture mostly absorbed through top and bottom layers, or through the edges? Does solder mask matter?
- During PB fabrication, how do heating cycles and other processes affect moisture content?
- When is dry storage necessary?
- How effective is our dry pack (bag with desiccant and humidity indicator card)?

Needs To Know (Cont'd)

- What is the maximum acceptable moisture content for safe soldering? (*not addressed in this study*)
- What does the Humidity Indicator Card (HIC) tell us? If blue, is it safe to solder? If pink, do we have to bake?
- How quickly does the finished PB absorb moisture in a shop environment? What about assembly operations?
- Do seasonal changes matter in the shop environment?
- How can we determine if maximum acceptable moisture content has been exceeded before soldering?
- If we have to bake, what temperature, and for how long?

Measuring Moisture With An Analytical Balance Can Help Answer These Questions

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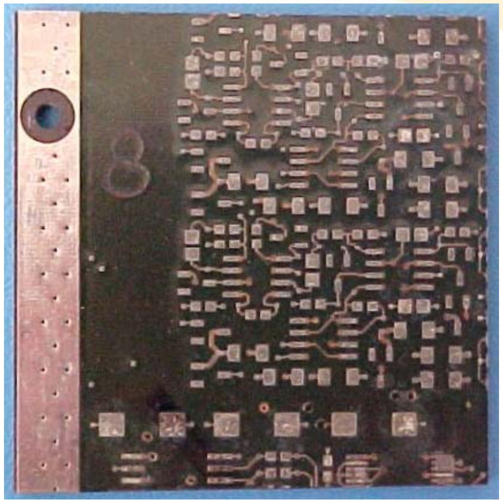
Experimental Method

- Weigh/bake/weigh to measure moisture content
- Samples:
  - About 2” square, 0.062” or 0.133” thick, sawed from finished PBs using waterjet (so copper doesn’t smear)
  - Three different commercially available laminate materials
  - Mixed technology (PTH with SMT), varying amounts of copper, no sequential lamination, microvias, or high aspect ratio holes



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Experimental Method (Cont'd)

	Spec	CTE-1	CTE-2	T_g
Laminate 1	IPC-4101/24, /126	45	220	180
Laminate 2	IPC-4101/24	70	320	175
Laminate 3	IPC-4101/24	75	250	170

Experimental Method (Cont'd)

- Equipment:
  - Circulating air oven capable of 100 ± 5° C
  - Analytical balance, capable of resolving .0001 grams
  - Clean tweezers and Nitrile gloves for handling samples
- To Establish Moisture Content:
  1. Establish a baseline "dry" weight by baking until most moisture has been eliminated, 48 hours at 100° C (Note: J-STD-020 suggests 48 hours at 125° C)
  2. Place the sample on the analytical balance, allow the reading to settle as much as possible, record to the nearest .0001 gram
  3. Weigh again at various stages in the process
  4. Subtract the measured weight from the dry baseline weight to determine moisture content, plot absorption or desorption

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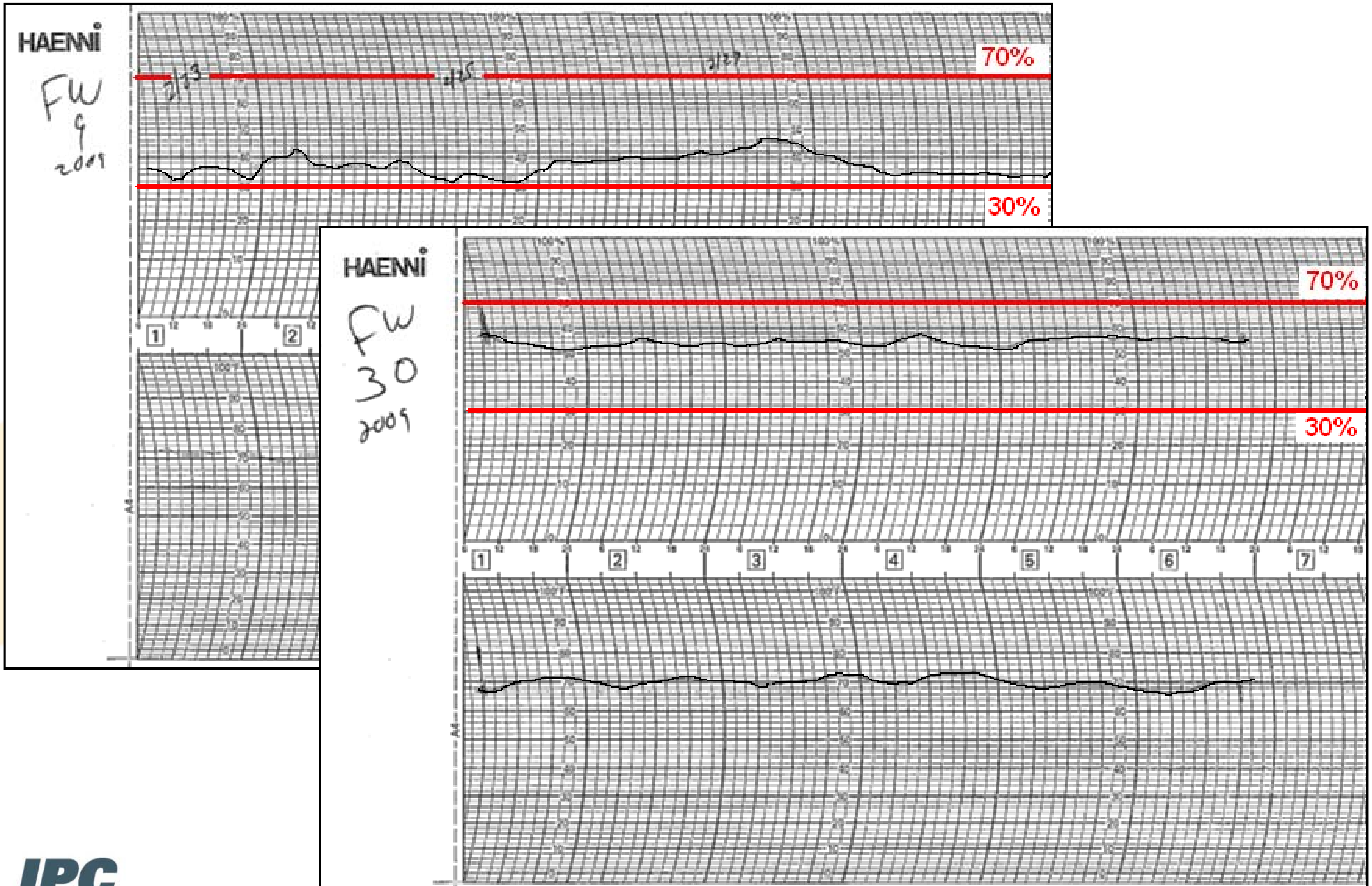
Experimental Limitations, Caveats

- A whole PB won't fit in an analytical balance
- Cu content in samples varies somewhat
- Environmental exposures were performed under shop conditions, not in a controlled humidity chamber
- It's difficult to determine moisture content deep within the substrate, so we don't necessarily know when boards are <u>completely dry</u> or <u>completely saturated</u>
- Environmental exposures reflect our shop conditions
- Samples were stored in pink poly bags to simulate common practice of some of our suppliers
- More samples were taken during initial phases, so the time scale on any given chart may not be consistent

Shop Ambient Conditions



Moisture Uptake In High Humidity

- Bake samples for 48 hours at 100 ± 5° C
- Weigh to determine "dry" baseline
- Expose samples to high humidity (suspend over a beaker filled with boiling deionized water)
- Remove samples periodically, weigh and record

Note: J-STD-020 soak for Level 1 is 168 hours at 85°C/85%RH

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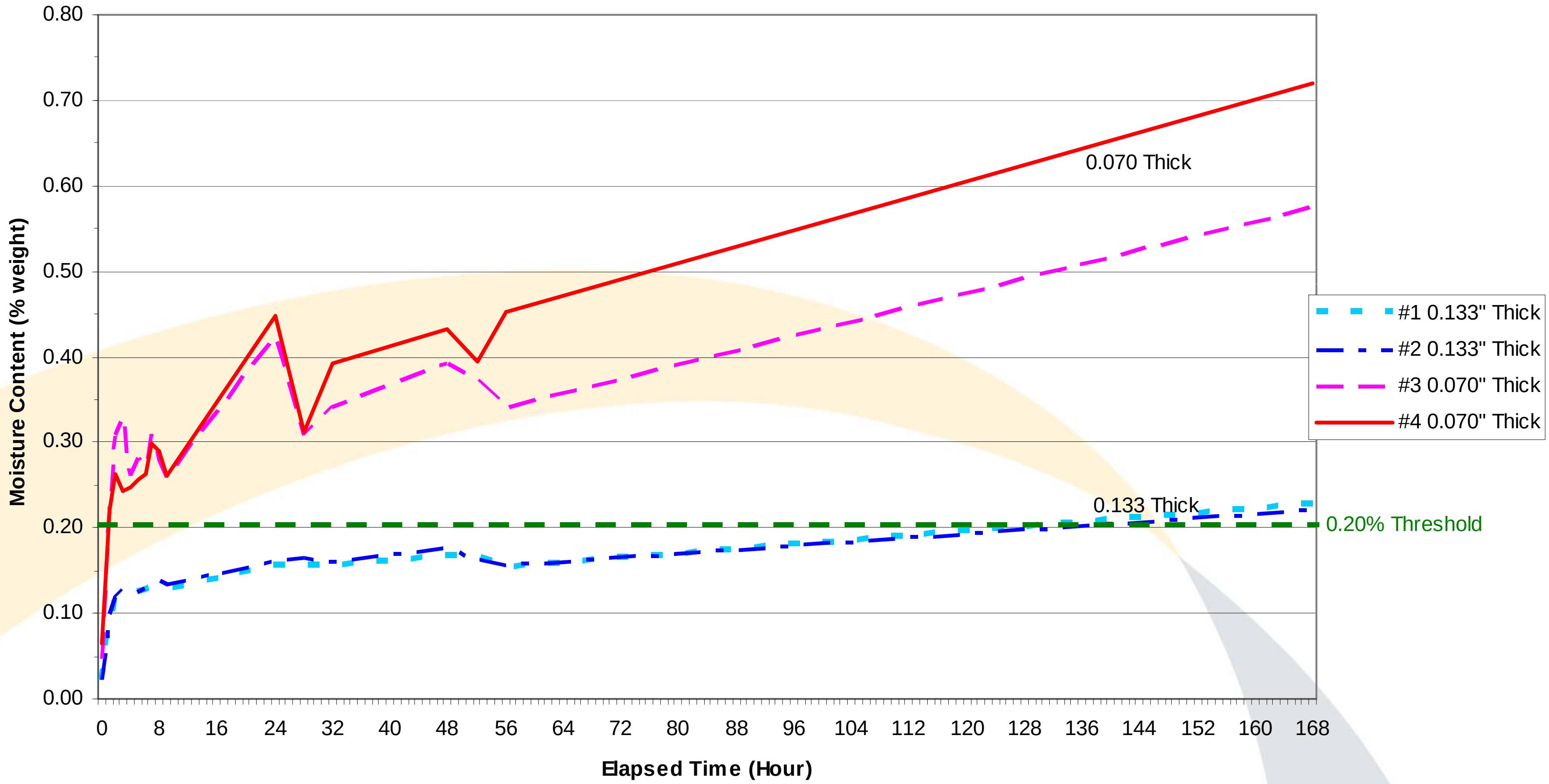
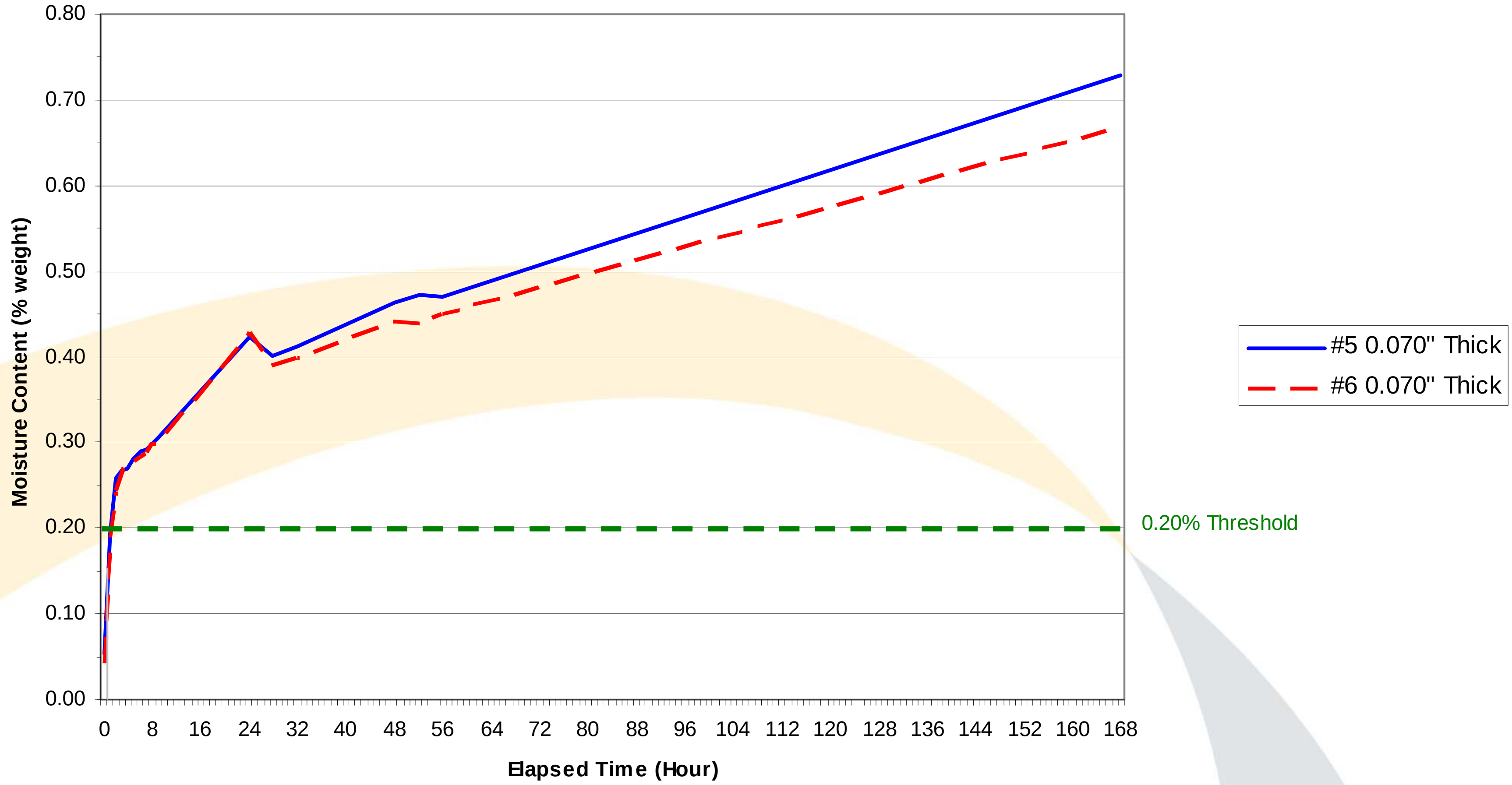
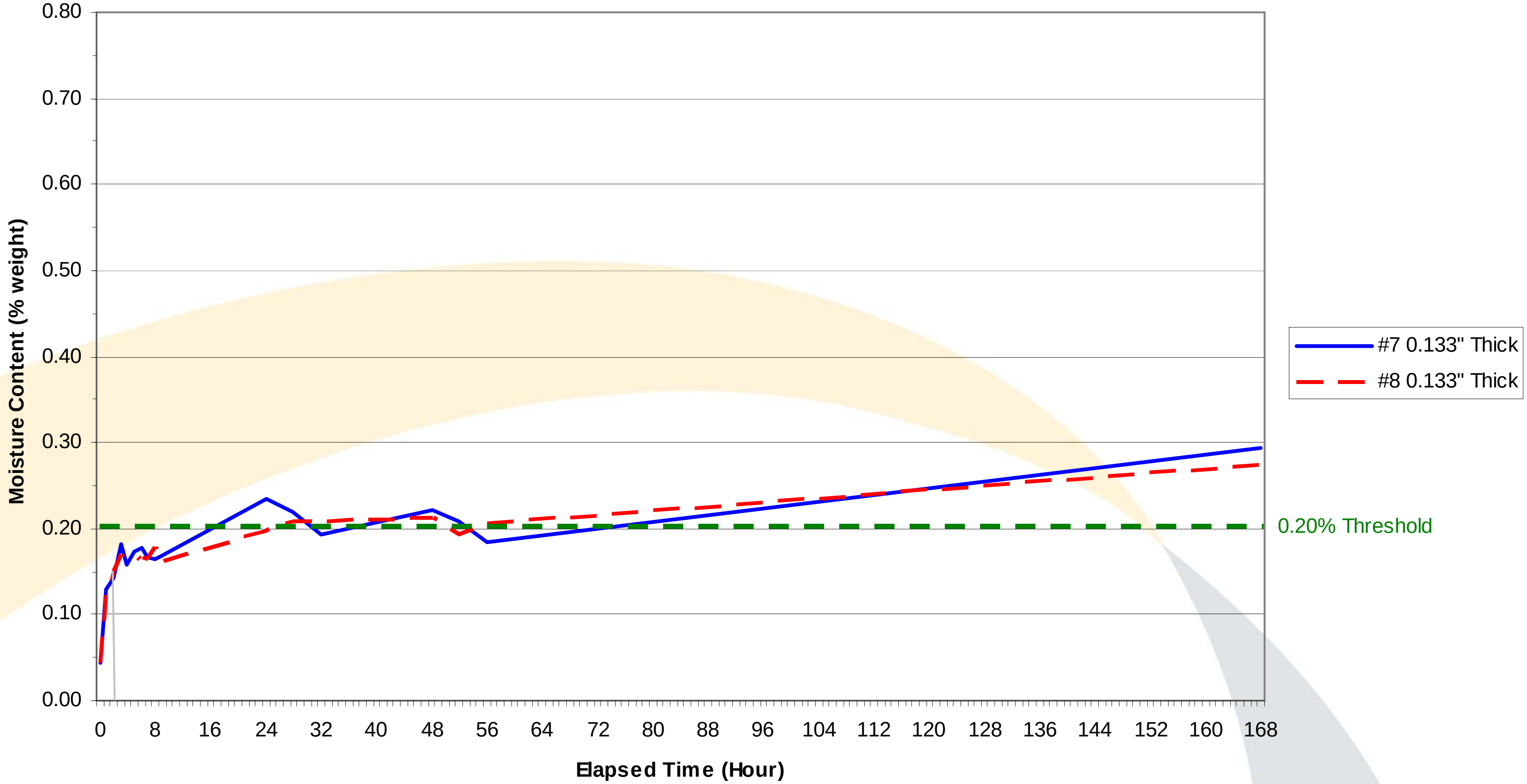
Moisture Absorption - Laminate 1



Moisture Absorption - Laminate 2



Moisture Absorption - Laminate 3



Moisture Absorption - Conclusions

- Laminates vary considerably in their capacities and rates of moisture absorption
- On a percent weight basis, a thicker PB absorbs moisture much more slowly

Note: Few measurements were taken as time approached 168 hours, but we know that samples were fairly “wet”

Water Vapor Desorption - Bakeout From A Wet State

- From the previous step, place saturated samples in an air circulating oven at 100 ± 5° C
- Weigh and record periodically

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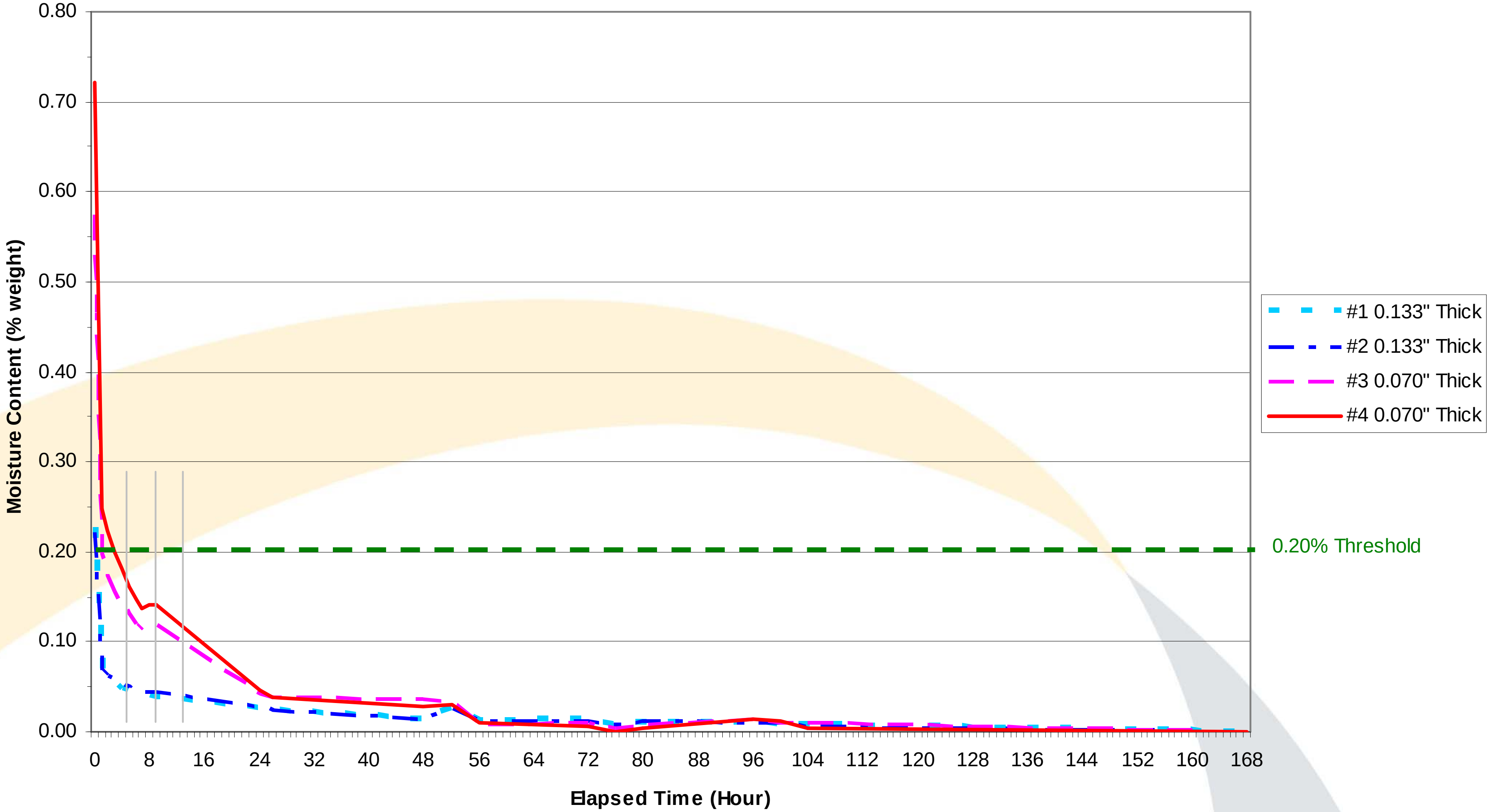
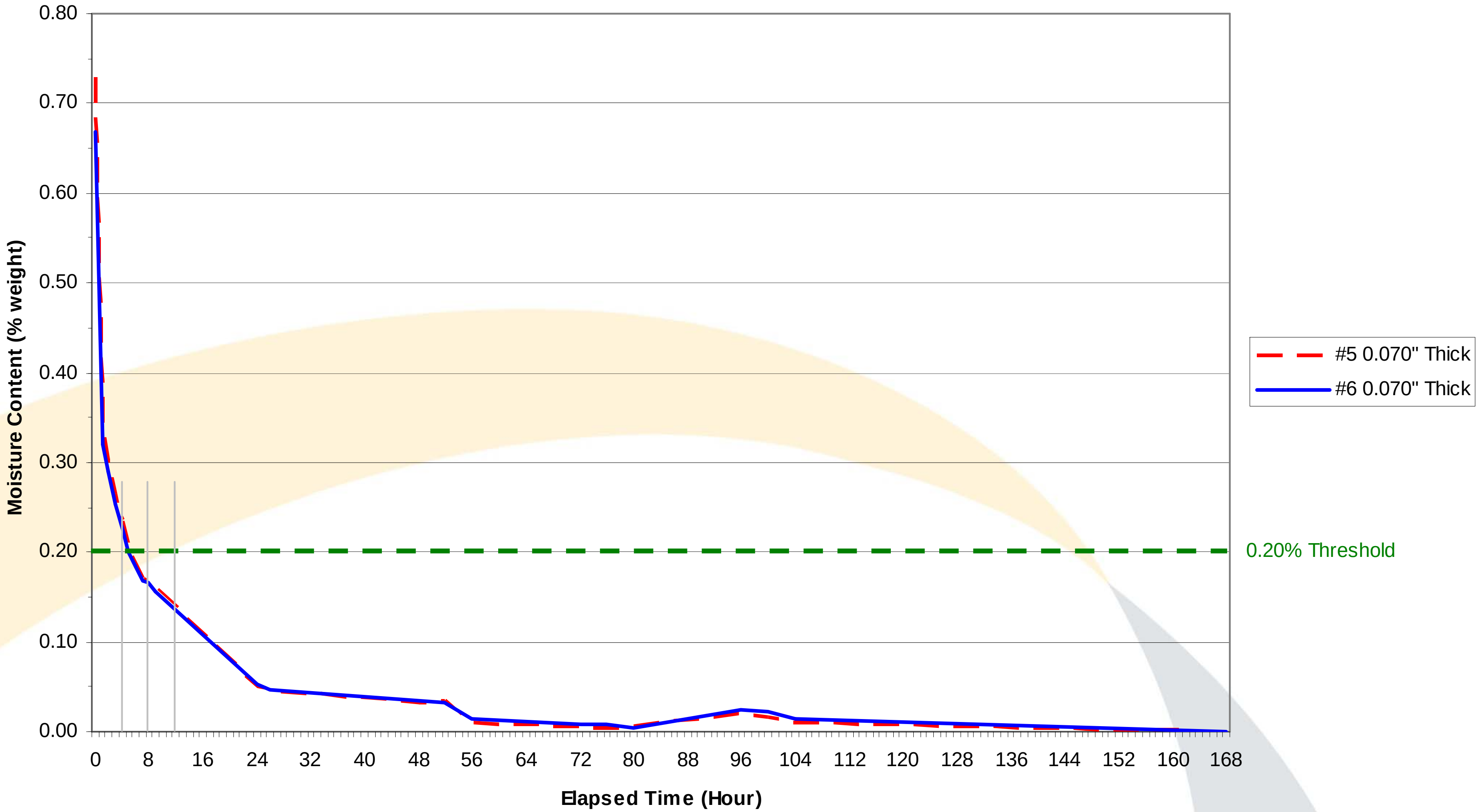
Desorption At 100ºC - Laminate 1



Desorption At 100ºC - Laminate 2



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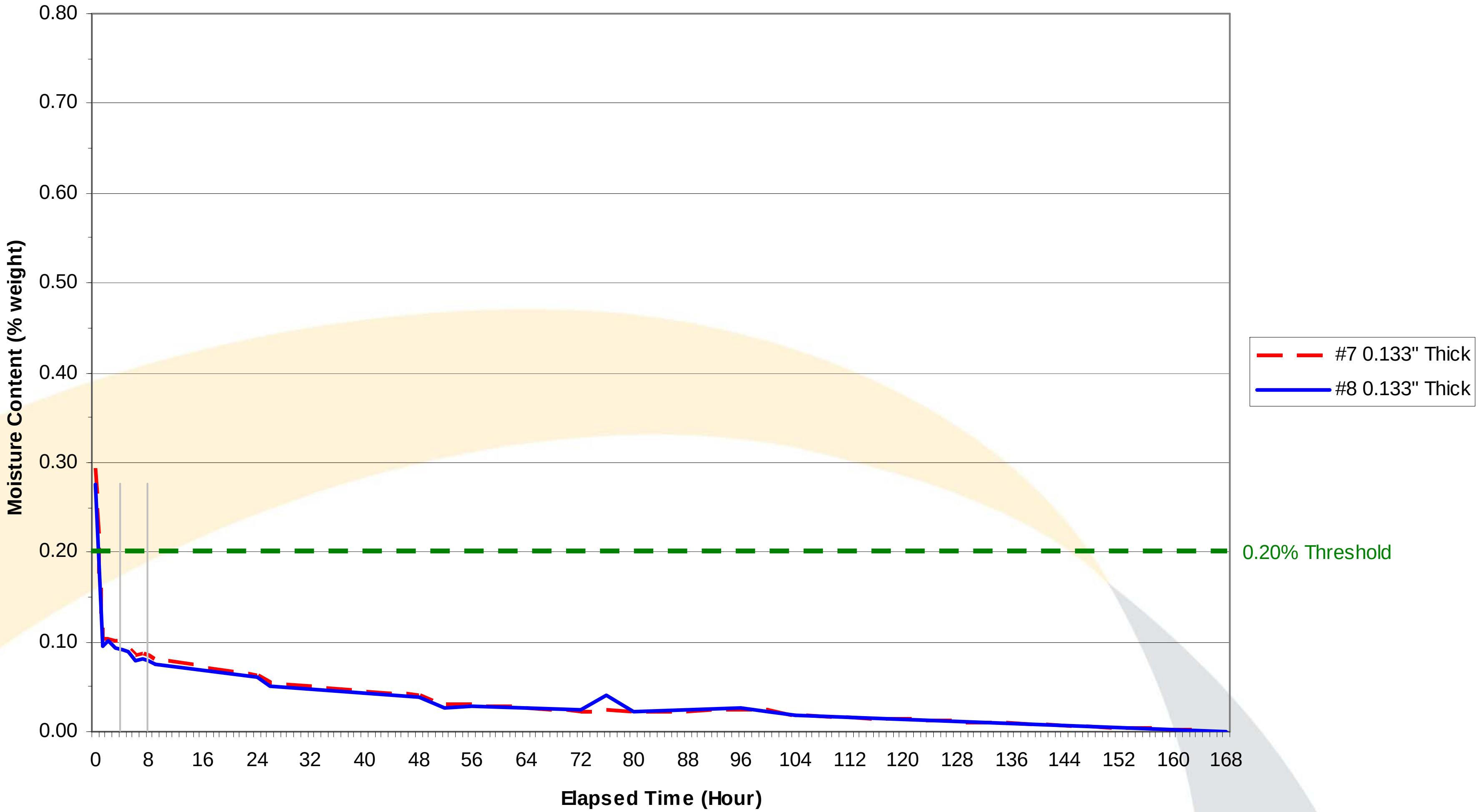
Desorption At 100ºC - Laminate 3



Water Vapor Desorption By Baking From A Wet State - Conclusions

- Moisture decrease is initially very rapid, indicating that outer surfaces hold much more moisture than inner ones
- Starting from a nearly saturated state, all samples fell below 0.20% moisture content within 6 hours
- For .070” thick PBs, 4 hours was sufficient for Laminate 1, whereas Laminate 3 took about 6 hours
- For .133” thick PBs, Laminate 1 baked out faster than Laminate 3
- 6-hour bake at 100° C should assure safe reflow for all of these boards, regardless of laminate, PB thickness, degree of moisture saturation, or whether the oven is inerted with nitrogen

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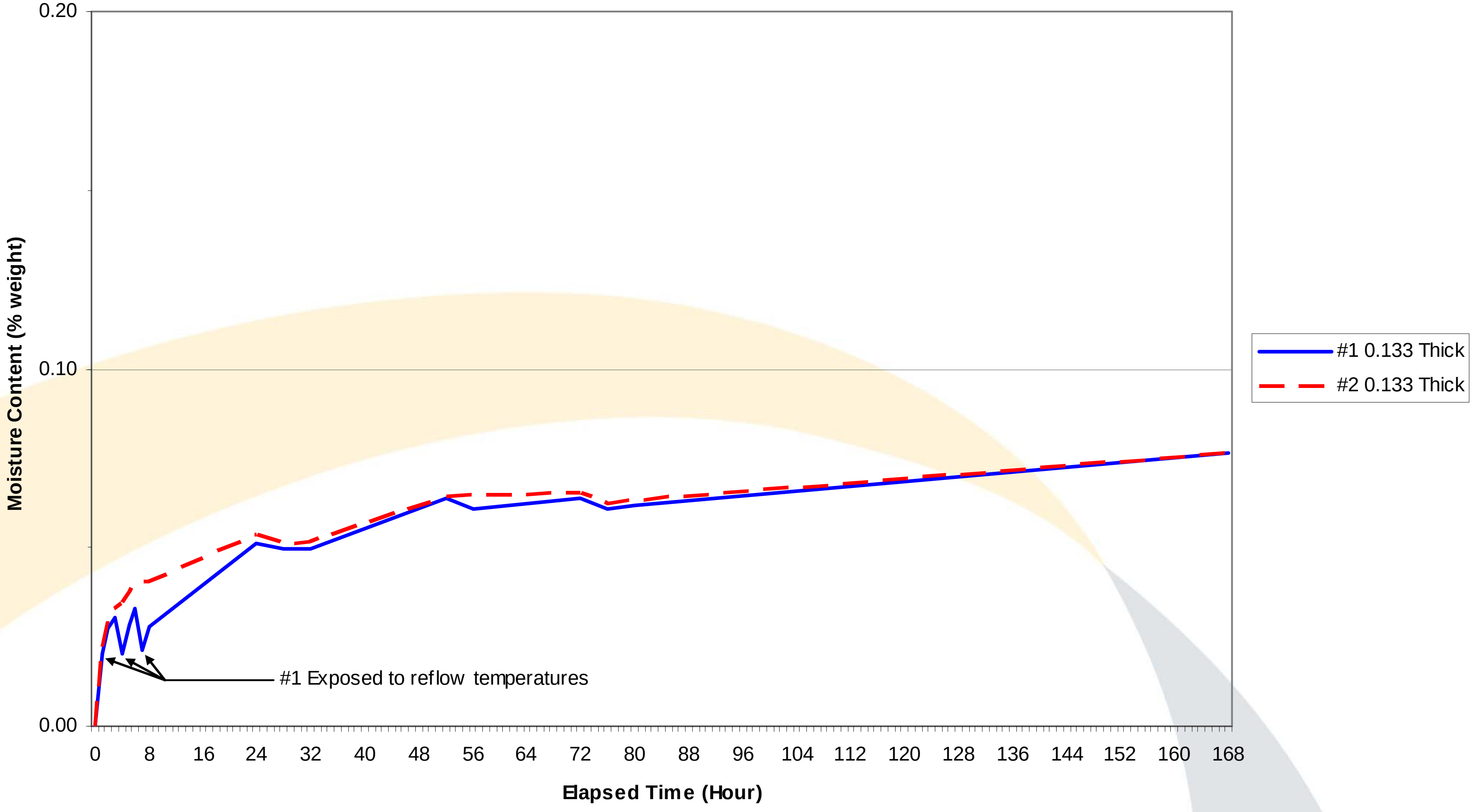
Moisture Absorption At Ambient

- From previous step, samples have been baked dry
- Subject two sets of samples to room ambient conditions (tabletop)
- Subject one of the two sets to 3 reflow cycles
- Weigh and record periodically
- Ambient RH: 12/8/08 to 12/15/08: 39% to 64%

Ambient Uptake - Laminate 1



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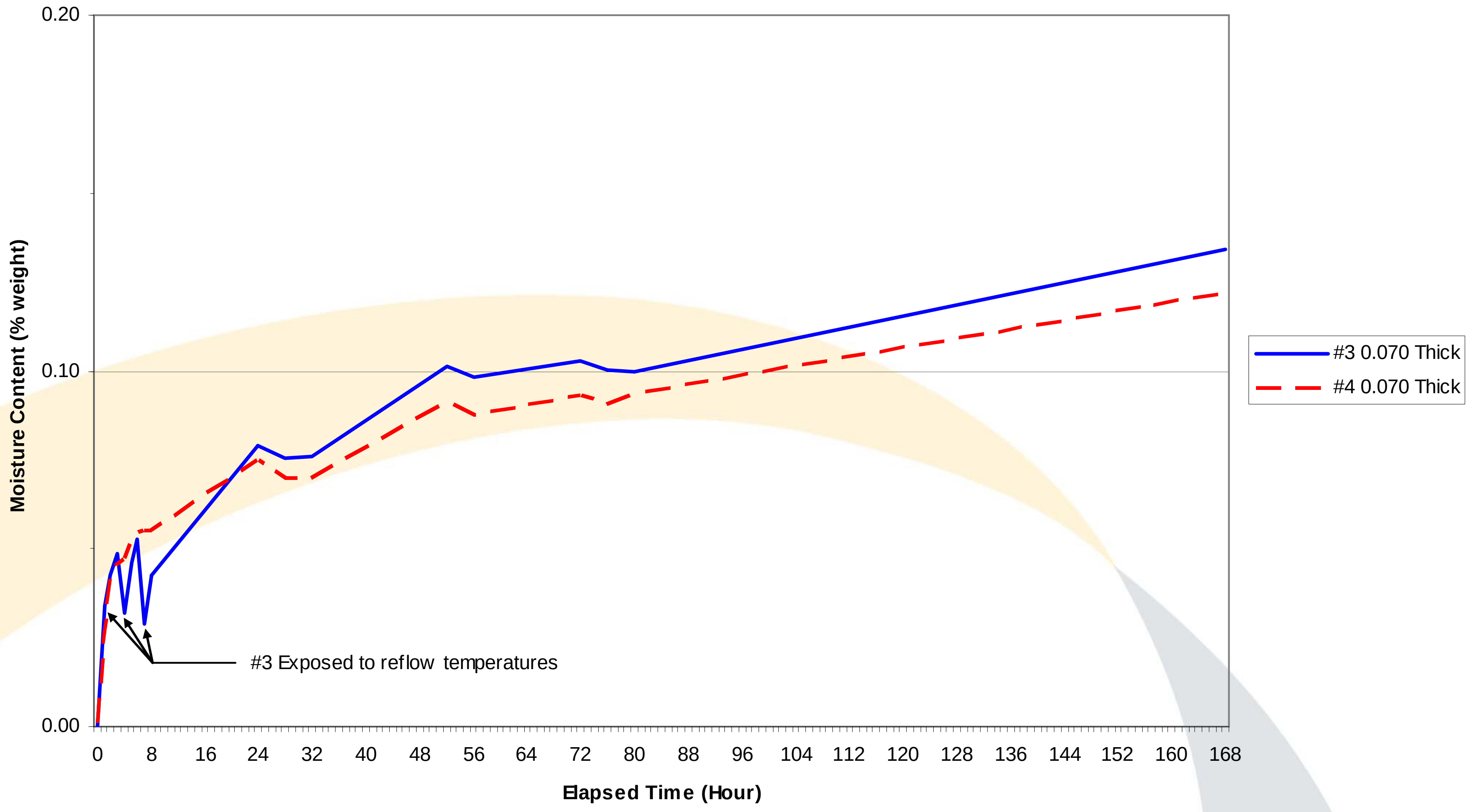
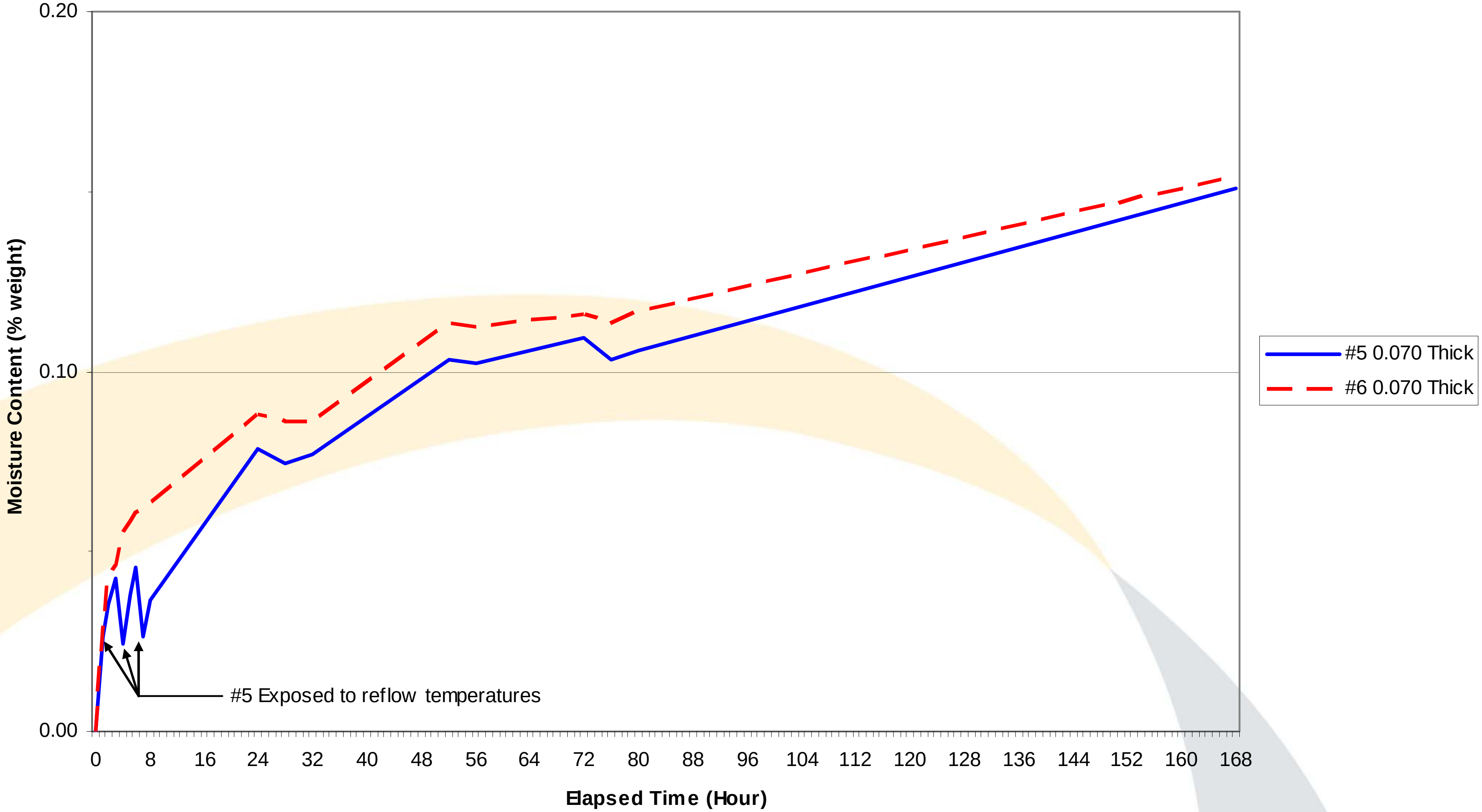
Ambient Uptake - Laminate 1



Ambient Uptake - Laminate 2



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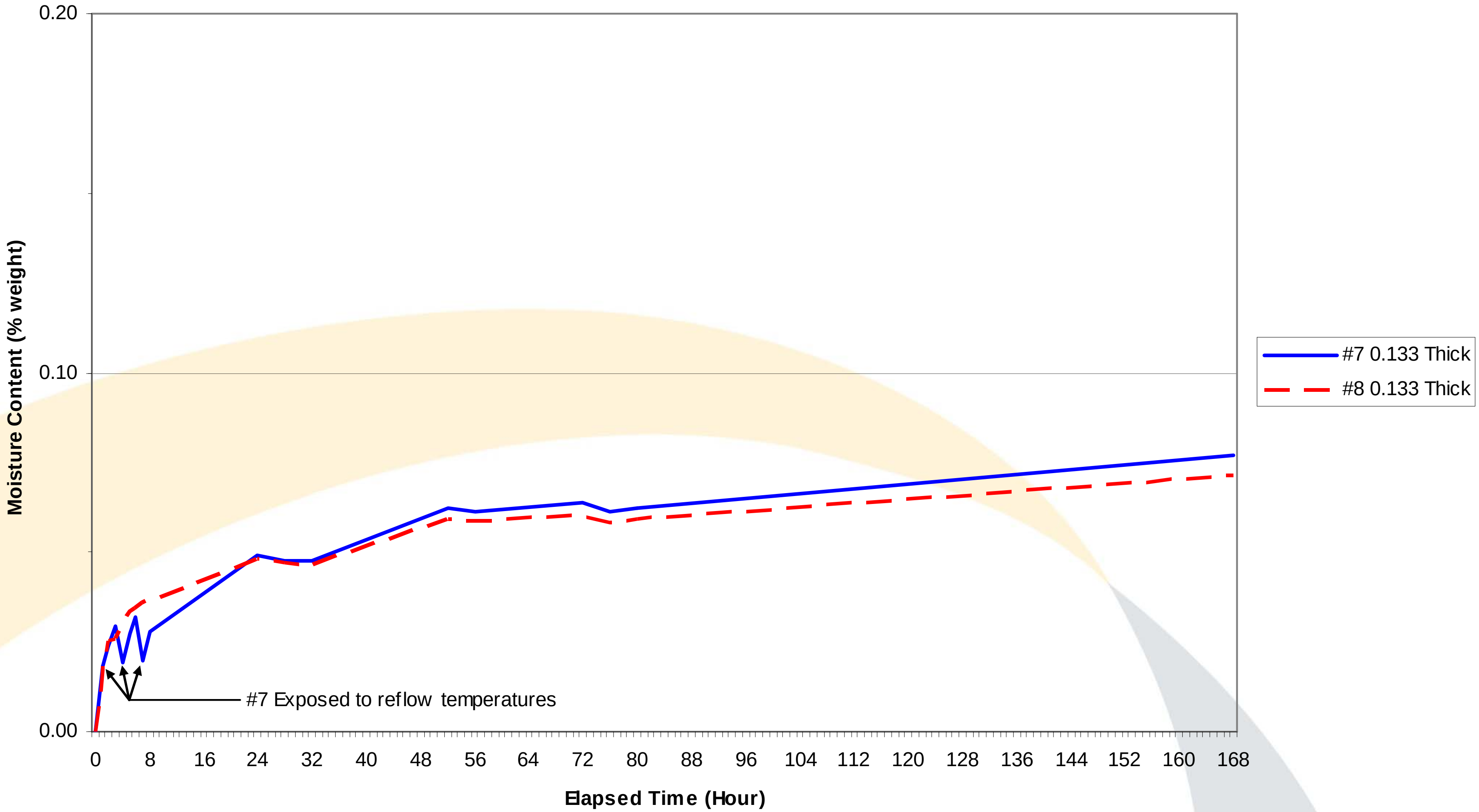
Ambient Uptake - Laminate 3



Moisture Absorption At Ambient - Conclusions

- Under normal winter conditions of 30 to 45% relative humidity in the shop, PBs can be left out of dry storage for at least 7 days before they reach 0.15% moisture content
- Of the three laminate materials, Laminate 2 was the worst, reaching 0.15% moisture in about a week
- Laminates 1 and 3 absorbed moisture much more slowly

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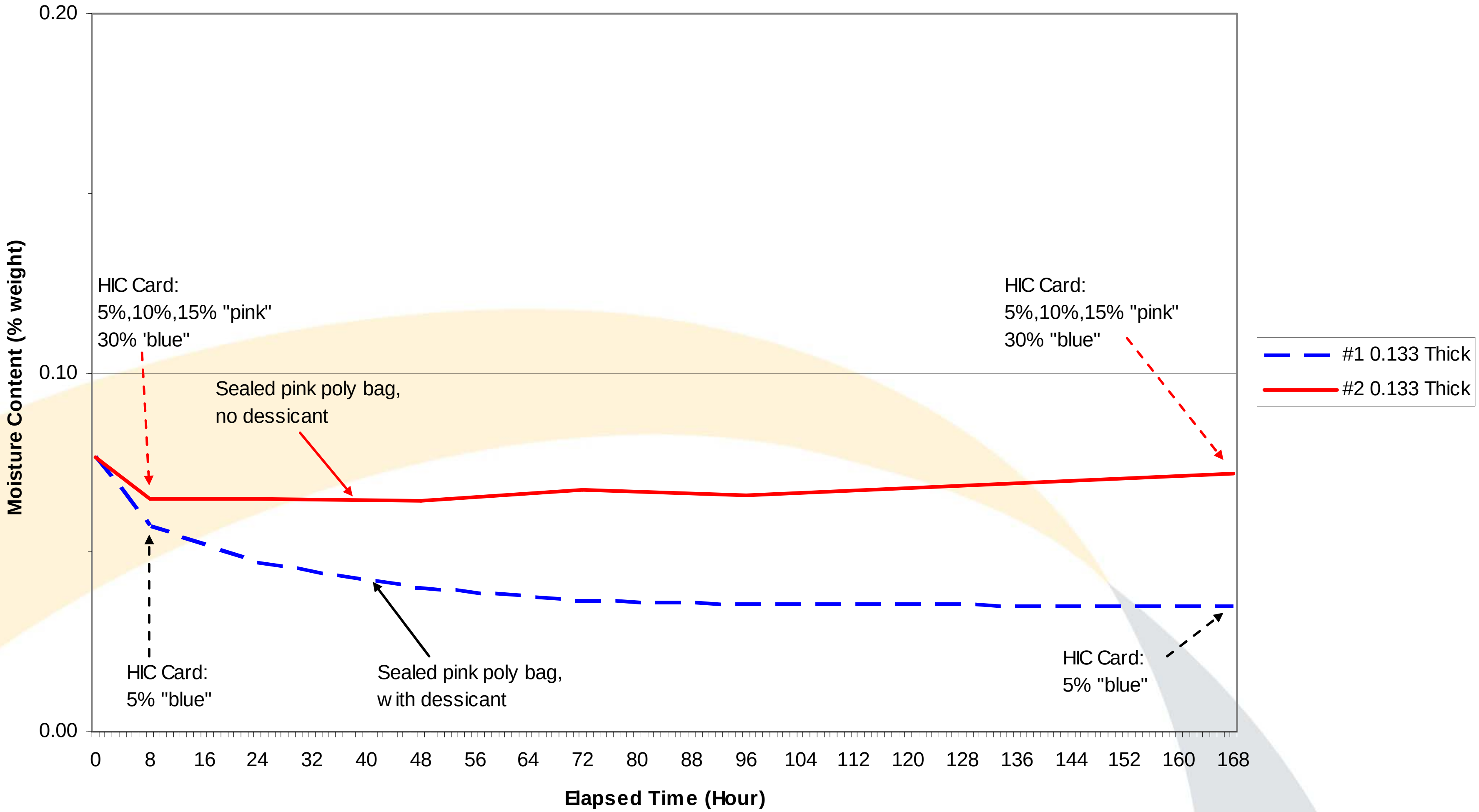
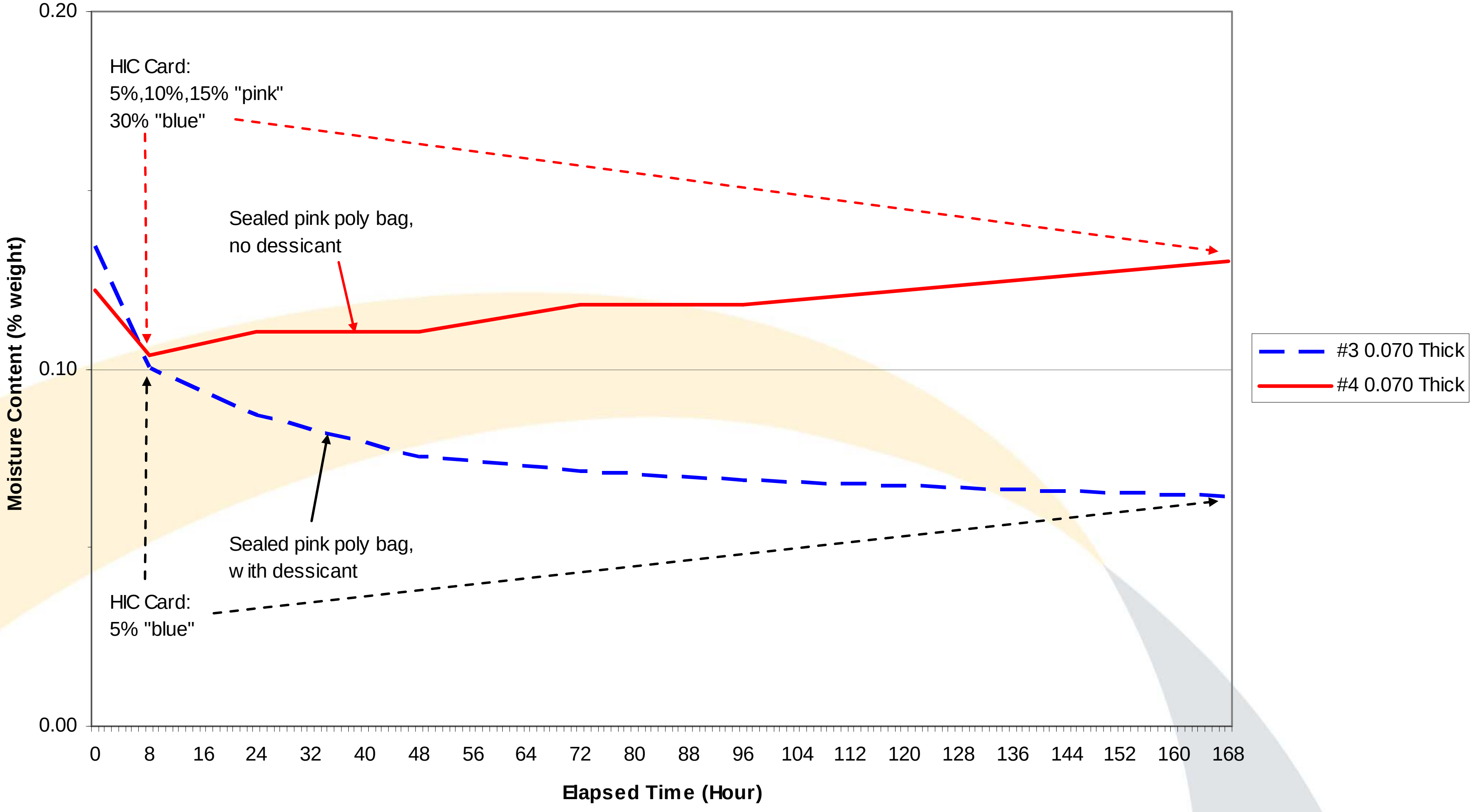
Absorption/Desorption In Bags

- Through the previous stage, boards have been exposed to ambient conditions
- Place one set in ziplock-sealed pink poly bag (6” x 8”) with desiccant and humidity indicator cards
- Place second set in ziplock-sealed pink poly bag with humidity indicator cards but NO desiccant
- In each bag, place one HIC with 5/10/15%RH dots, one with 30/40/50
- Up to four samples per bag, loose, with some contact
- Weigh and record at intervals
- Ambient RH: 1/5/09 - 1/17/09 36% to 60%

Bag Environments - Laminate 1



Bag Environments - Laminate 1



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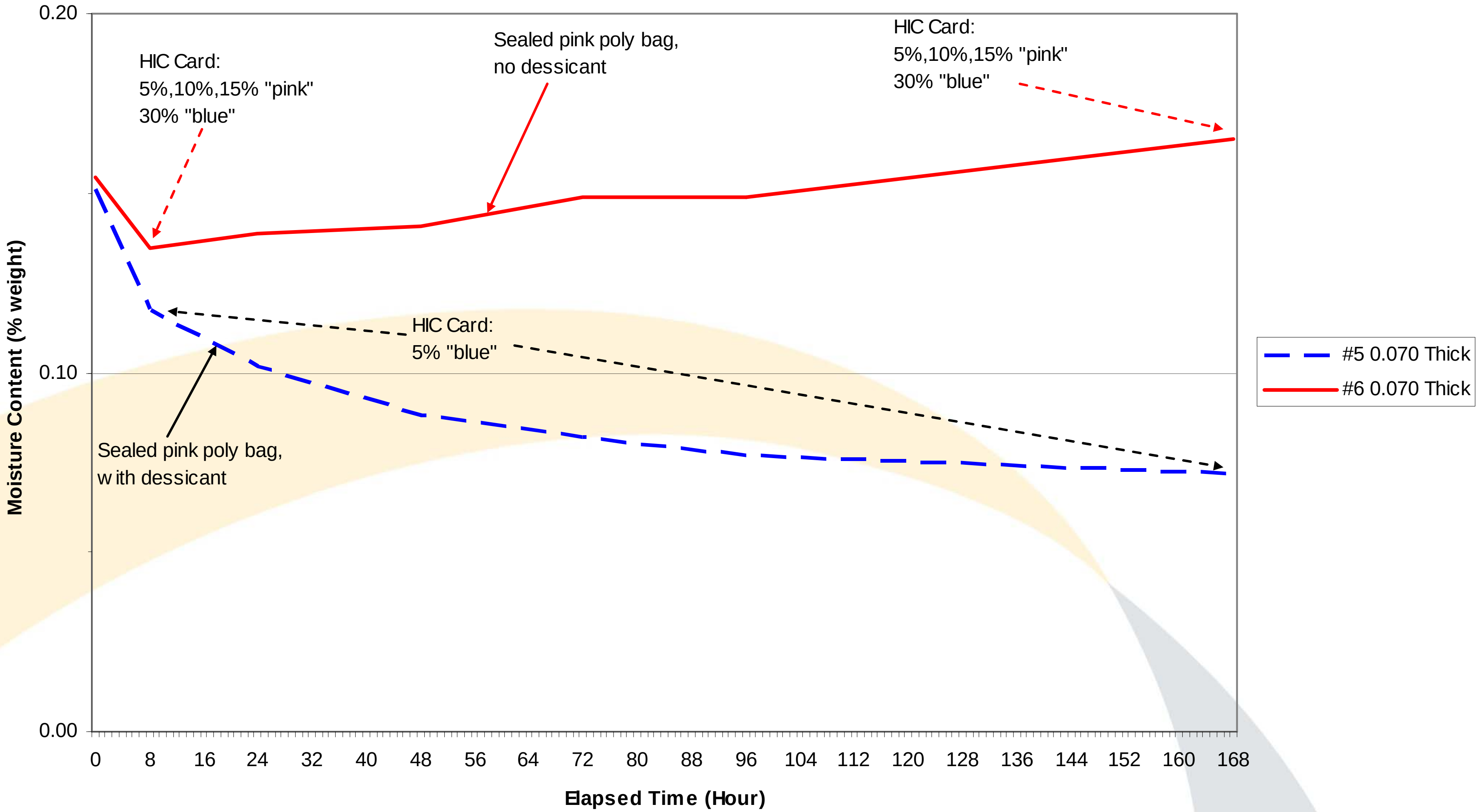
Bag Environments - Laminate 2



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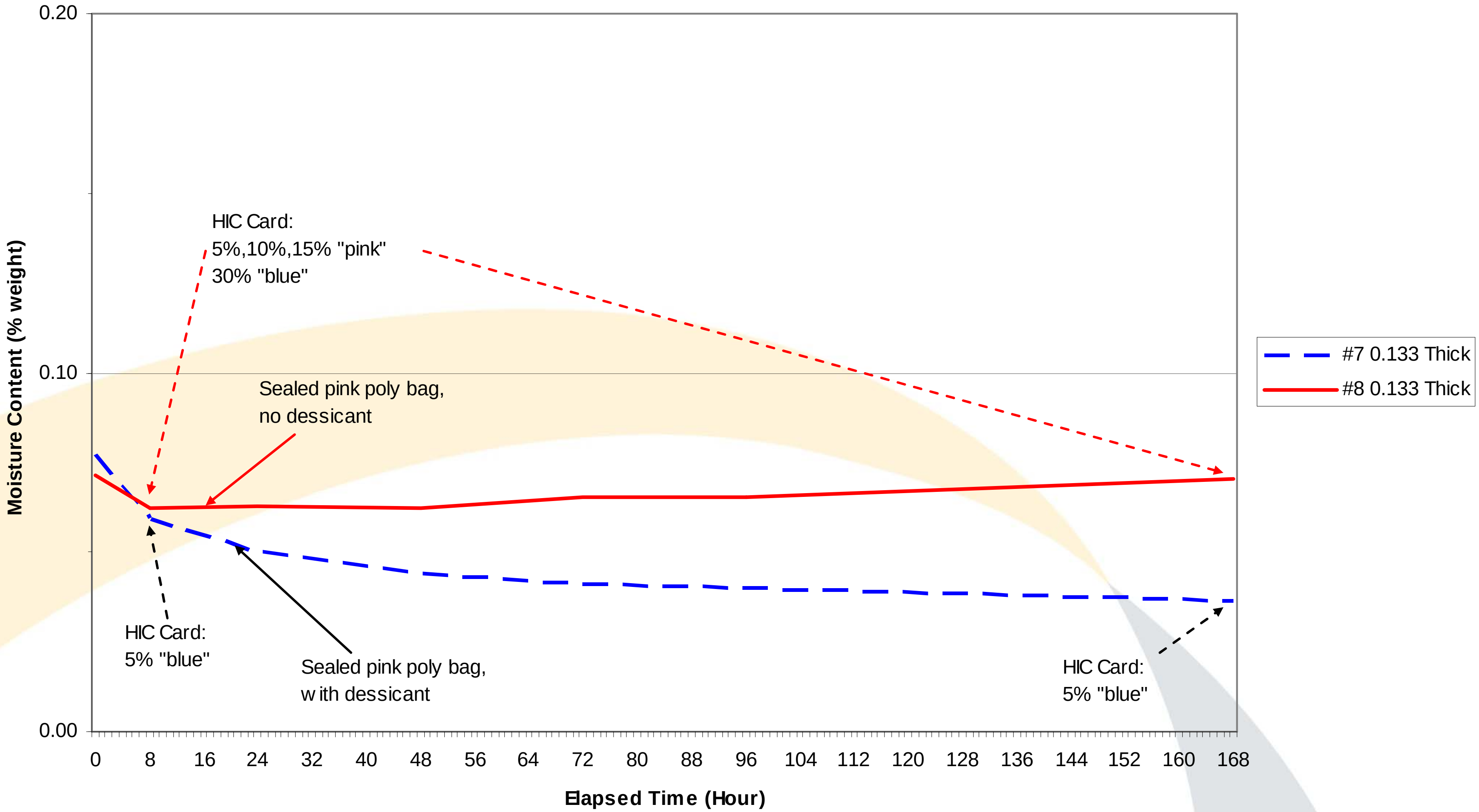
Bag Environments - Laminate 3



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Bag Environments - Conclusions

- Pink poly material slows down moisture vapor transmission, but is not an effective moisture barrier
- Without desiccant, the environment inside a pink poly bag quickly reaches equilibrium with ambient conditions
- When used with desiccant, a pink poly bag makes an effective dry pack, at least over short time scales
- The low humidity environment inside a dry pack will remove moisture from a PB
- A 30/40/50 HIC will not indicate a failure of the dry pack over a short time scale, but a 5/10/15 card will show a change

Humidity Indicator Cards

- One set, bake dry (24 hours at 100° C)
- Second set, expose to high humidity (95%RH, 30 to 60° C) until they reach a moisture content that is representative of boards exposed to shop ambient
- Split these sets:
  - Half in ziplock pink poly, with desiccant and HIC
  - Half in ziplock pink poly, HIC but NO desiccant
- Weigh and record at intervals
- Ambient RH 1/5/09 - 1/15/09: 38% to 60%

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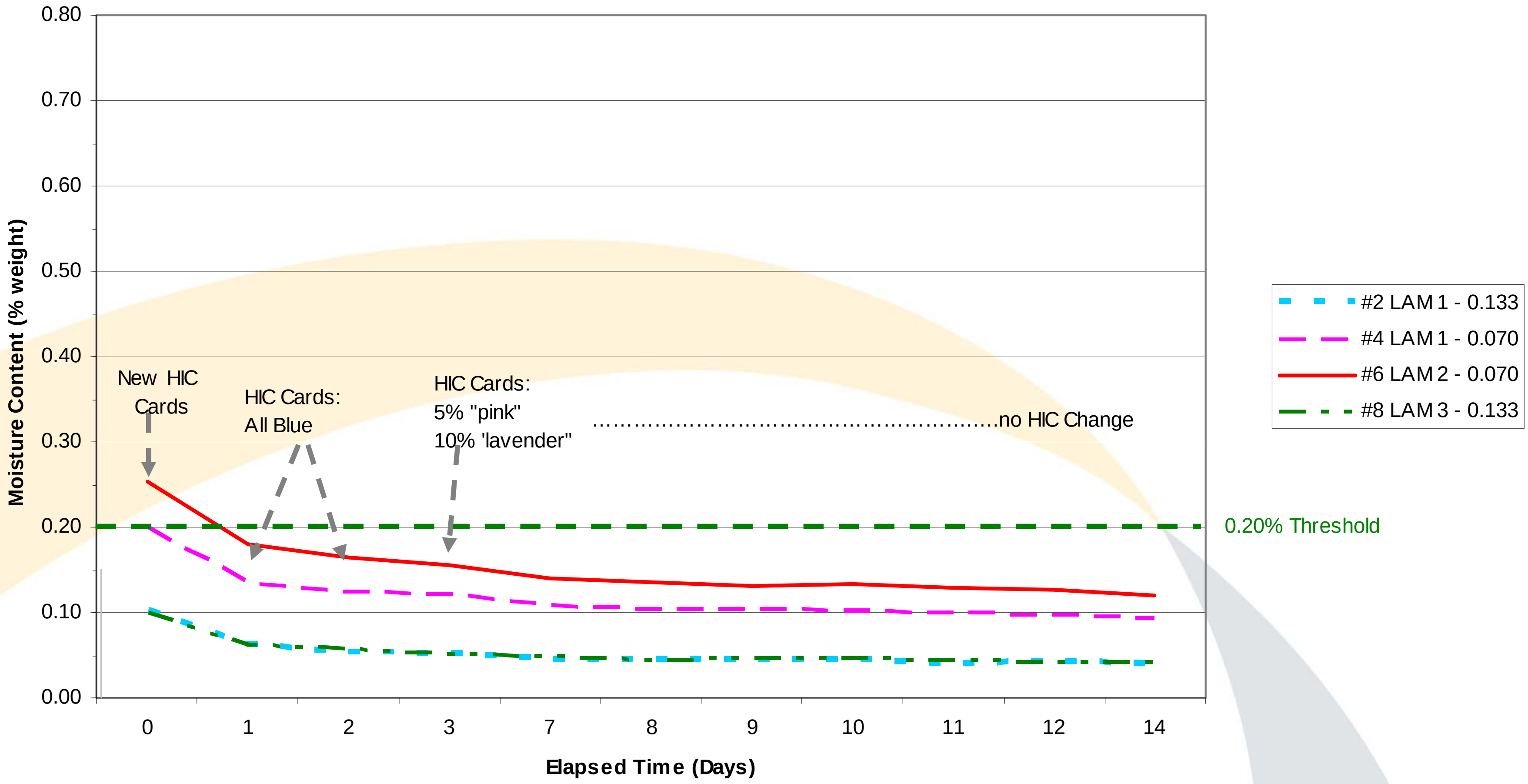
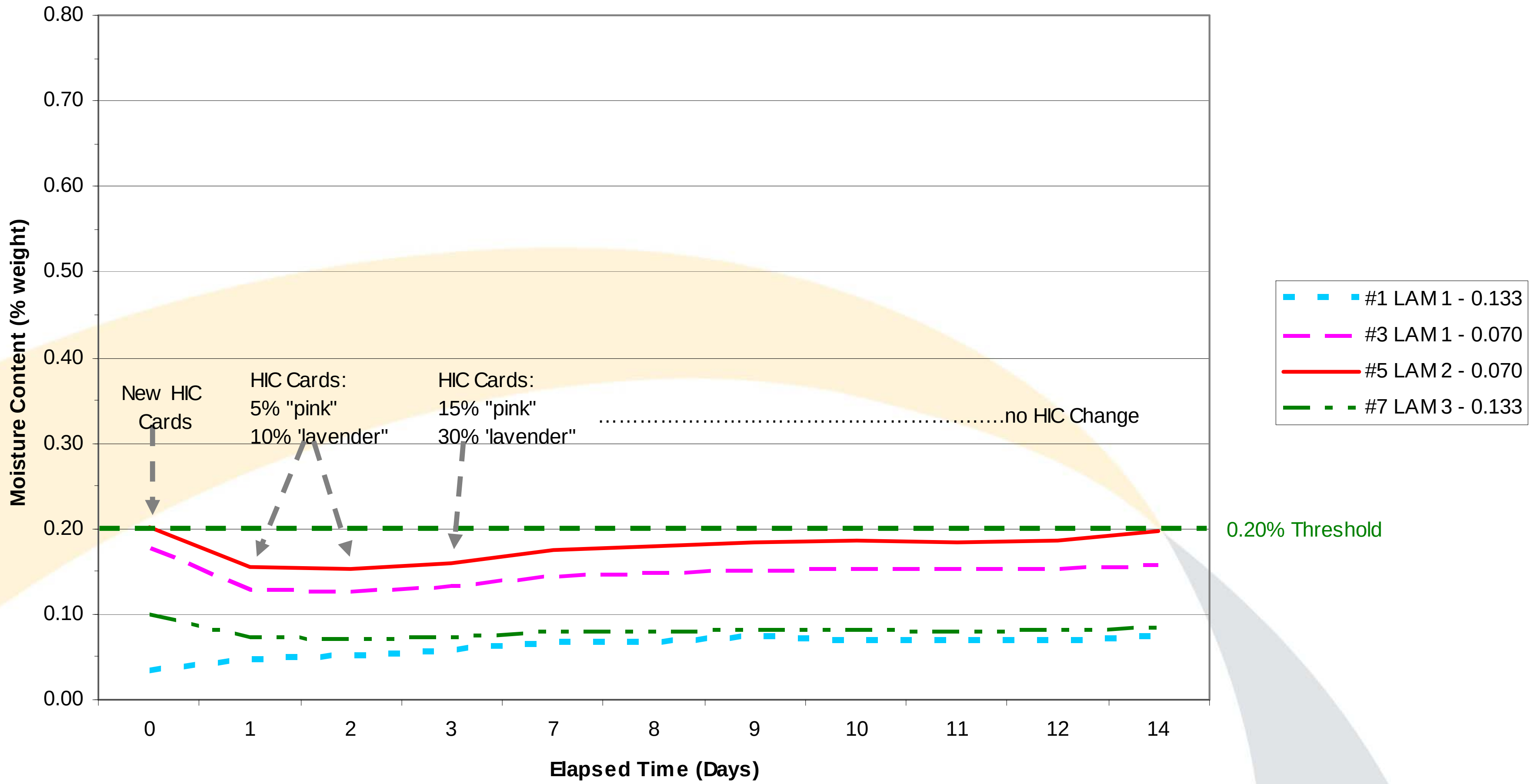
HIC - Wet With Desiccant



HIC - Wet Without Desiccant



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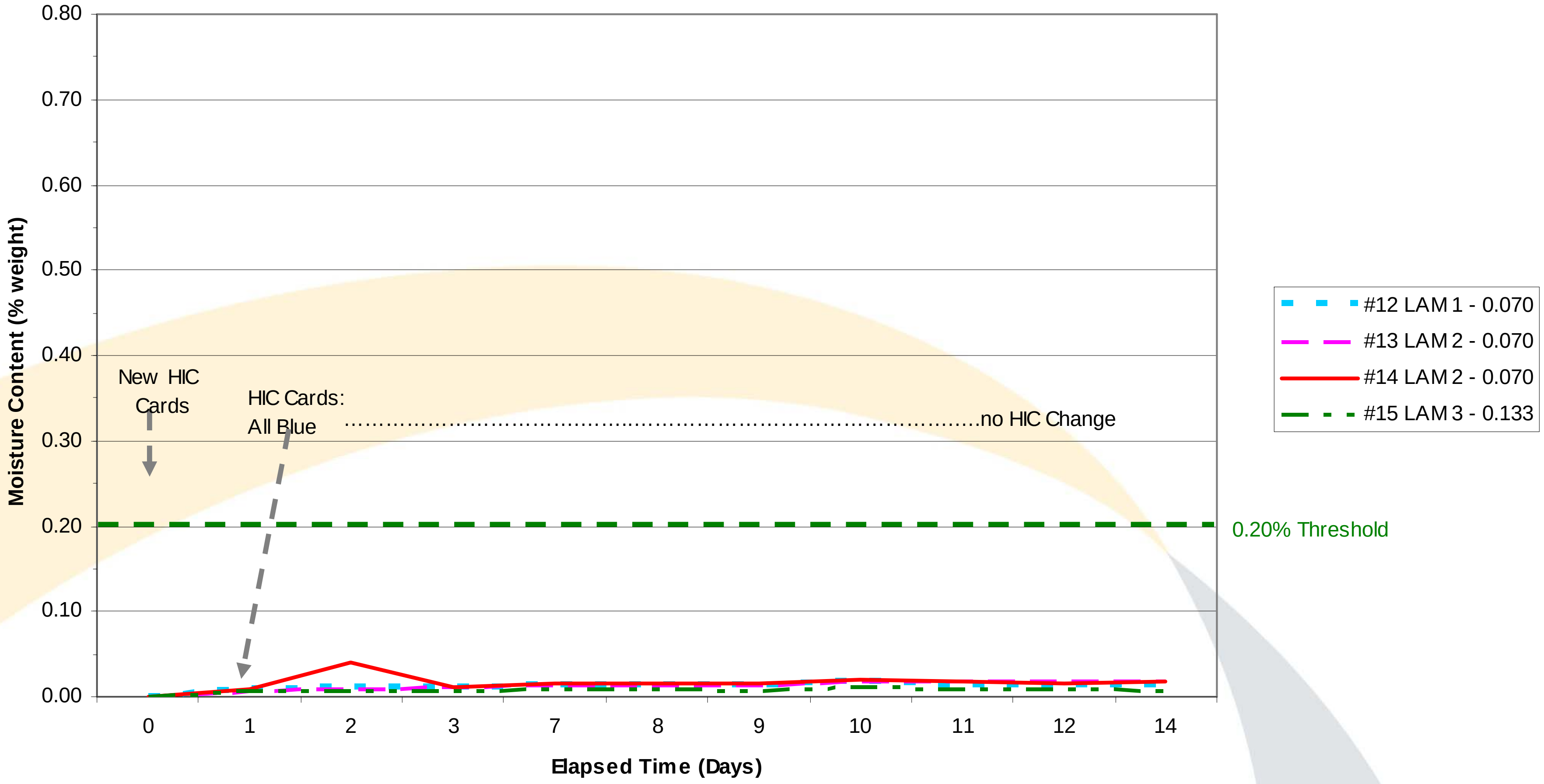
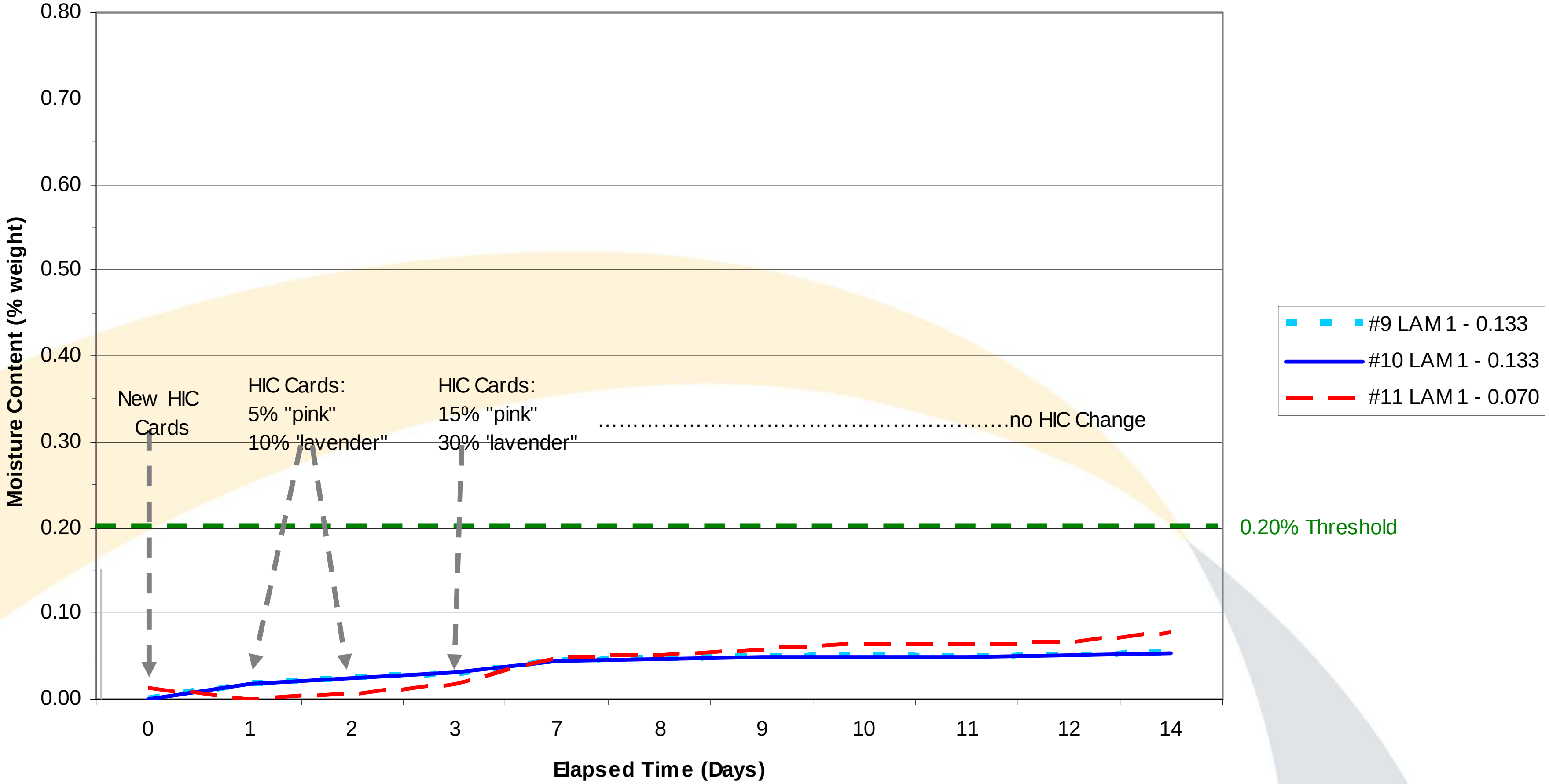
HIC - Dry With Desiccant



HIC - Dry Without Desiccant



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HIC Experiments - Conclusions

- Exposing samples to high humidity saturates samples slower than the steaming beaker
- If a “wet” PB is placed in a dry pack with desiccant, a 5/10/15 HIC will change
- If a PB is placed in a bag without desiccant, a 5/10/15 HIC will change fairly quickly as moisture is absorbed through the bag
- Moisture desorption out of a “wet” PB is faster than transmission through the bag from the atmosphere
- The HIC measures the environment inside the bag, not the moisture content inside the board

Long-Term Ambient Exposure

- With samples that started out “dry” in the previous step, continue ambient exposure (from day 25)
- Samples that started with desiccant, replace with fresh desiccant
- Samples without desiccant, continue without
- Weigh and record at intervals
- Ambient RH 1/30/09 - 7/15/09: 30% to 73%

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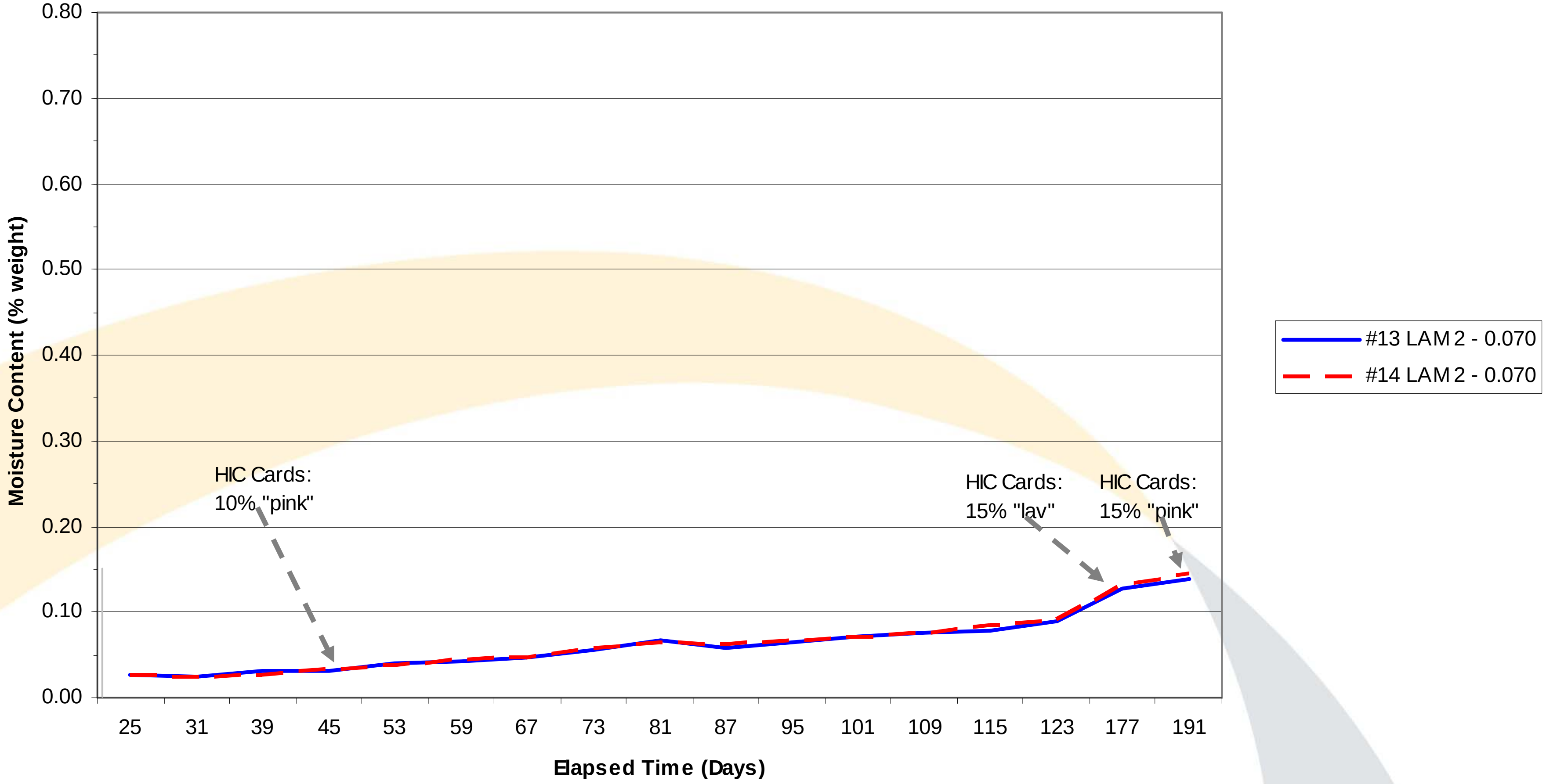
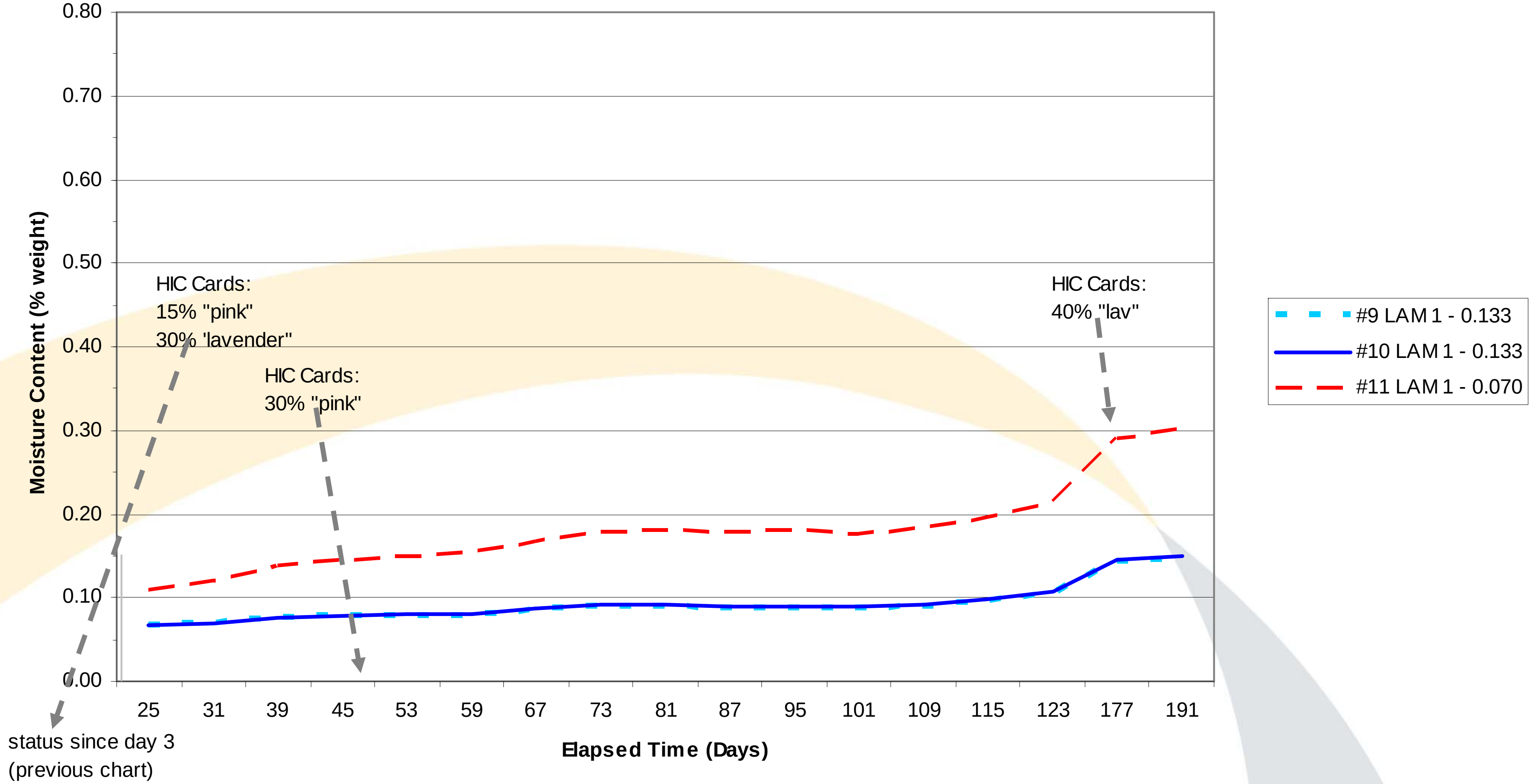
Ambient Exposure - With Desiccant



Ambient Exposure - Without Desiccant



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Long-Term Exposure - Conclusions

- Samples with the same laminate and same thickness, exposed to the same conditions, track very closely in moisture absorption
- A PB that starts out dry will stay dry in a pink poly bag with desiccant for many months
- With or without desiccant, PBs absorb more moisture during warm summer months
- Pink poly may be a less effective moisture barrier in higher ambient relative humidity

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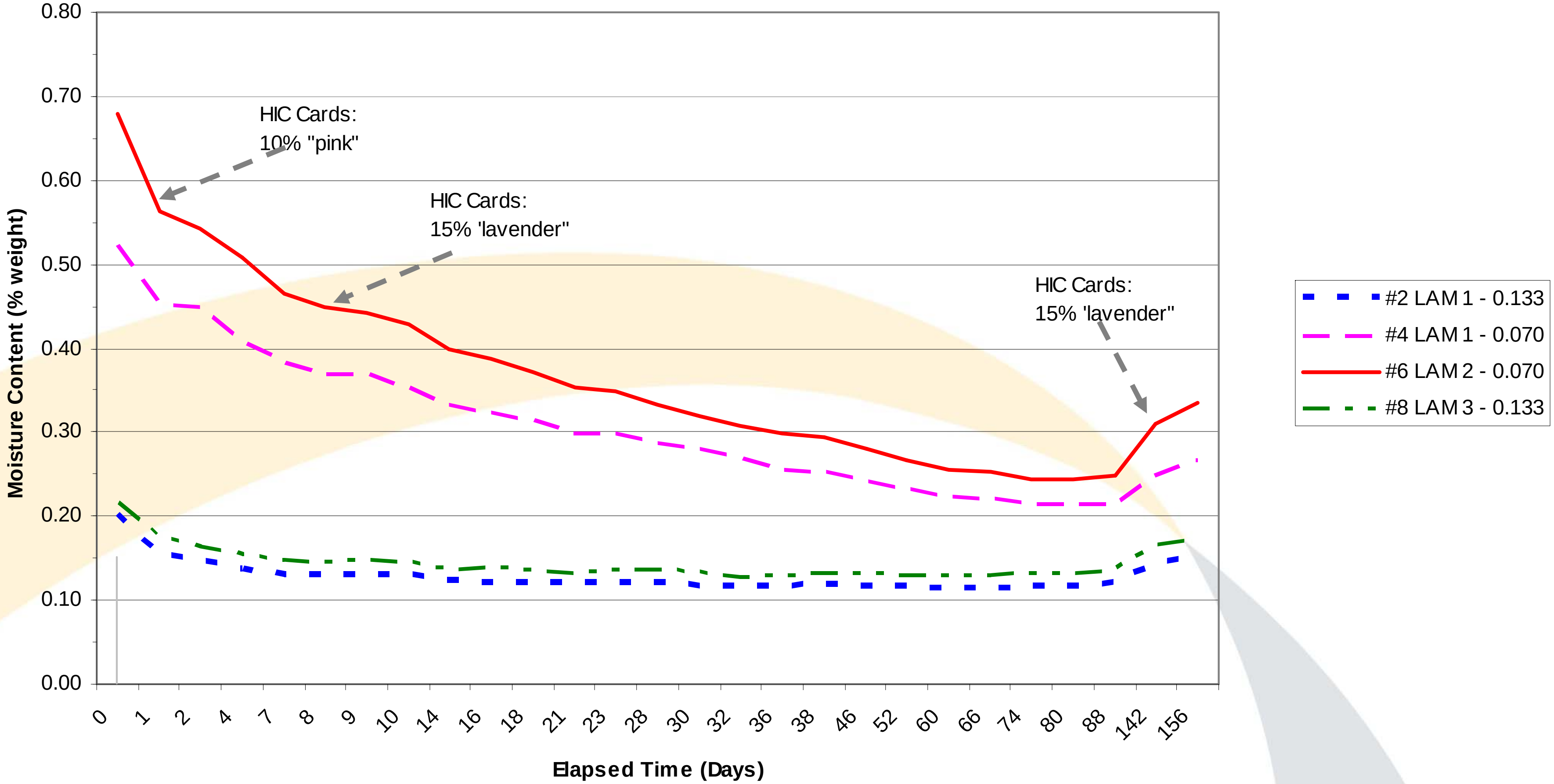
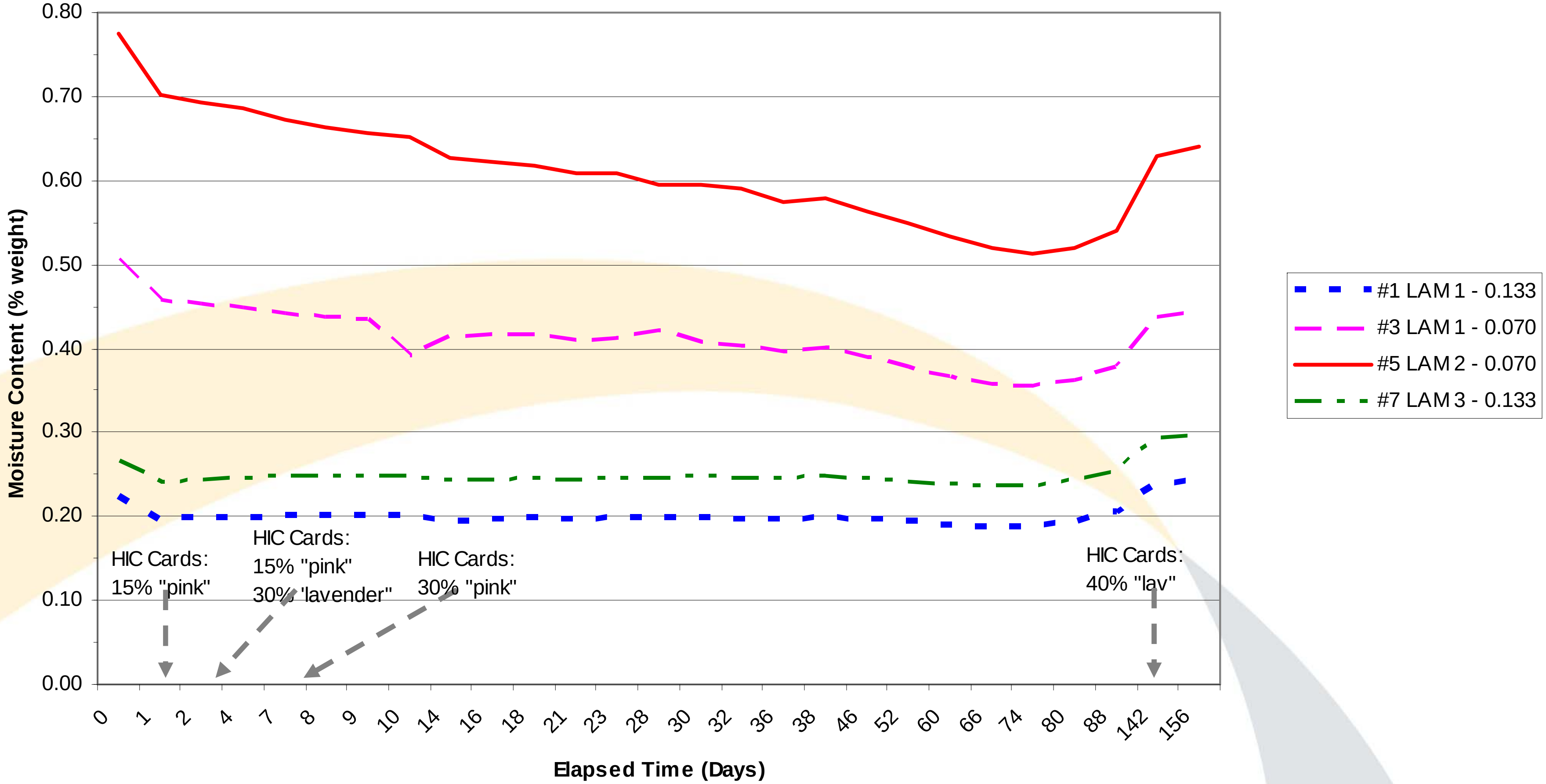
Long-Term Moisture Release In Bags

- Saturate samples in humidity chamber (95% RH, cycle 30 to 60° C for 10 days)
- Split these sets:
  - Half in ziplock pink poly, with desiccant and HIC
  - Half in ziplock pink poly, HIC but NO desiccant
- Weigh and record at intervals
- RH: 2/9/09 - 7/15/09: 30% to 73%

Moisture Release, Bags With Desiccant



Moisture Release Without Desiccant



Long-Term Moisture Release In Bags - Conclusions

- Samples with same laminate and thickness do not start out equally “saturated”
- Moisture content in a thicker PB stays fairly constant
- Desiccant will dry out a wet PB, but only over many months, and only for so long
- Samples that start out wet or dry, with or without desiccant, all increased in moisture content during summer months, suggesting that the reason is moisture transmission through the bag, not saturation of the desiccant

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Absolute Weight Gain

- If moisture is absorbed significantly at board edges, we should expect that a thicker board will absorb water more quickly
- If moisture is mostly absorbed through top and bottom surfaces, board thickness should make little difference
- To determine the effect of board thickness alone, plot data for the absolute moisture content, rather than as a proportion of the total weight

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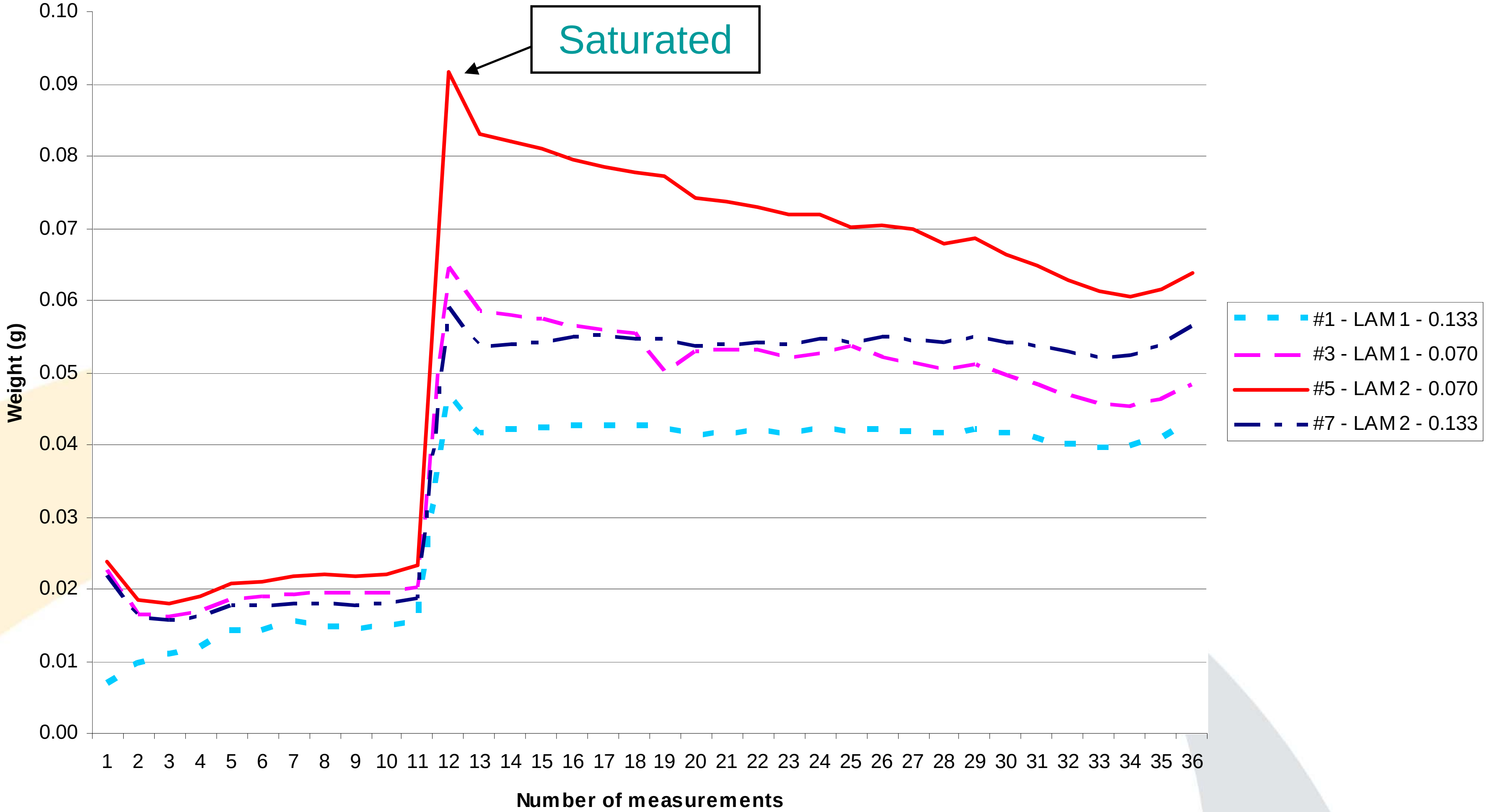
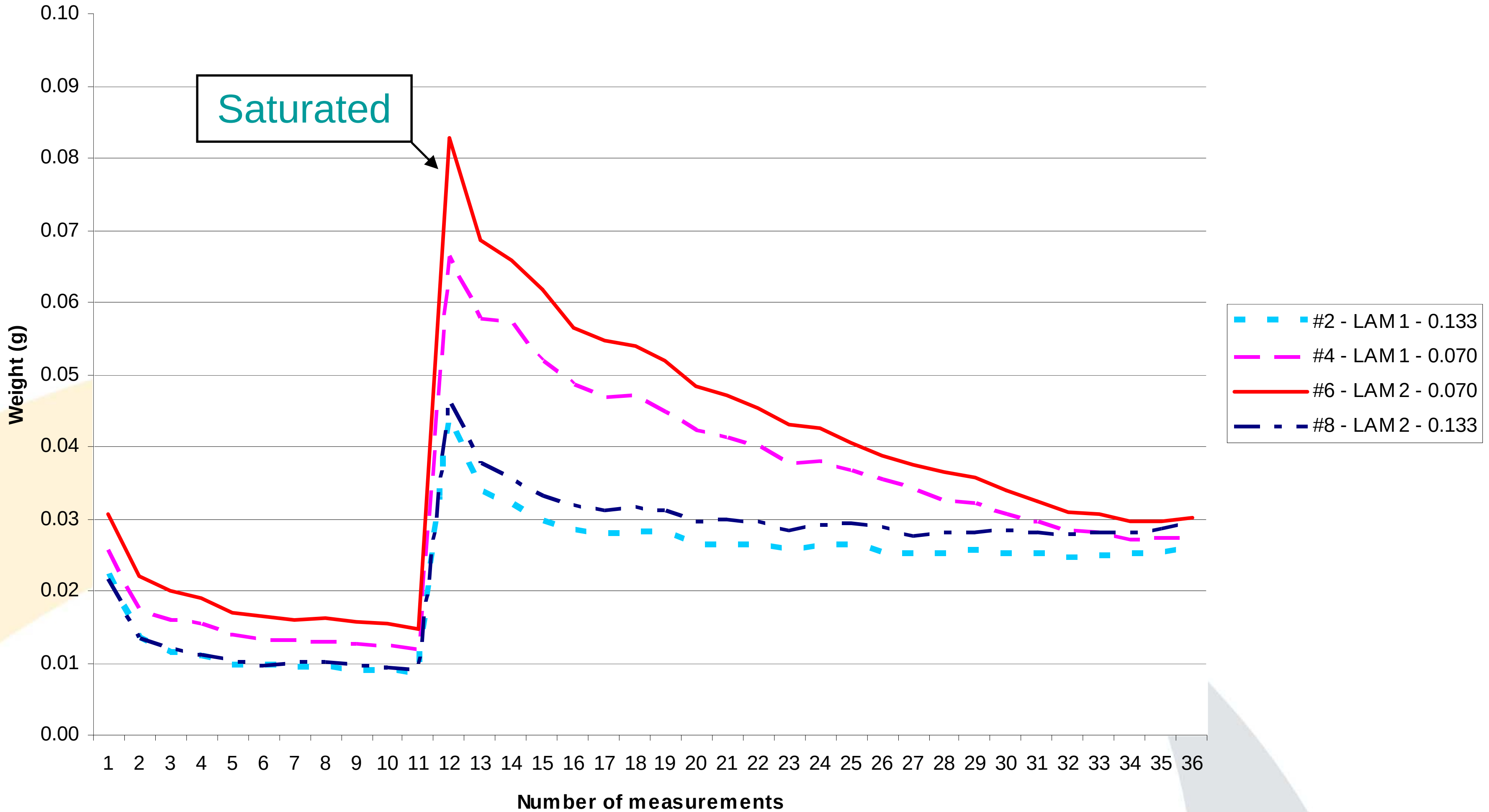
Weight Gain, Stored Without Desiccant



Weight Gain, Stored With Desiccant



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Absolute Weight Gain - Conclusions

- Contrary to expectation, thinner boards gained more moisture than thick ones

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Questions For Future Work

- Does a saturated board reach equilibrium at all depths, or is there a gradient ("Fickian" or non-Fickian)?
- Is there a better way to measure moisture content on full-size PBs? Measurements using IR or other parts of the EM spectrum are foiled by copper.
- Why do thinner boards absorb more absolute moisture?
- How do we measure or estimate the copper content in a PB or a sample?
- What are the effects of the copper in plane layers?

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QUESTIONS?