


Evaluating Moisture and Corrosion Risk in Hermetic Packages

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Method 1018 limits moisture to 5000 ppmv



- **What does this mean?**
- **Where did the limit come from?**
- **How well does it predict corrosion risk?**

Review of the basics:



- **RGA**: residual gas analysis – A technique for determining the amount of each kind of vapor molecule by mass spectrometry
- **Relative abundance RA** (ppm_v): A way of reporting the amount of a particular kind of vapor molecule by comparing it to the sum of all kinds
 - “v” means by volume rather than by mass.
 - RA is used to report RGA results.
 - Example: if 10% of all the vapor molecules in a container are water molecules, the RA of water molecules is 10%, *regardless of the pressure*.
 - In an evacuated system, relative abundance of water is close to 1 million ppm_v .

Basics review, continued



- **Partial pressure:** Contribution to total press. by any particular kind of vapor molecule – measurable in atm.
- **Saturated vapor pressure:** Measure of the *maximum possible* partial pressure at a specified temperature – can be looked up in a table.
 - Independent of total pressure.
 - Water examples: 0°C, 0.006 atm; RT, 0.03 atm; 100°C, 1 atm.

Basics review, continued



- 5000 ppmv is the same thing as 0.005 atm (*if* ref to 1 atm).
- **Relative humidity (RH)**: One way of reporting moisture level. Compares moisture level to the maximum possible level at the temperature of interest.
 - RH: a measure of how close a vapor is to condensing, corrosion risk. (RA is *not*).
 - $RH = \text{Partial press} \div \text{Sat vap press}$.

Method 1018 Summary



1. Hold hermetic package at 100°C for 12 - 24 hours (to establish eq'm partial pressure of water vapor).
2. Position package so that when punctured, all vapor inside will expand into the vacuum system.
3. Note system pressure rise upon puncture.
4. Use RGA to determine RAs of each variety of vapor molecule (Ar, H₂O, N₂, etc.).
5. Infer internal pressure of package before puncture from system pressure rise and package volume.
6. Can calculate partial pressure of water vapor from RA and internal pressure (often omitted).

Evaluation of corrosion risk



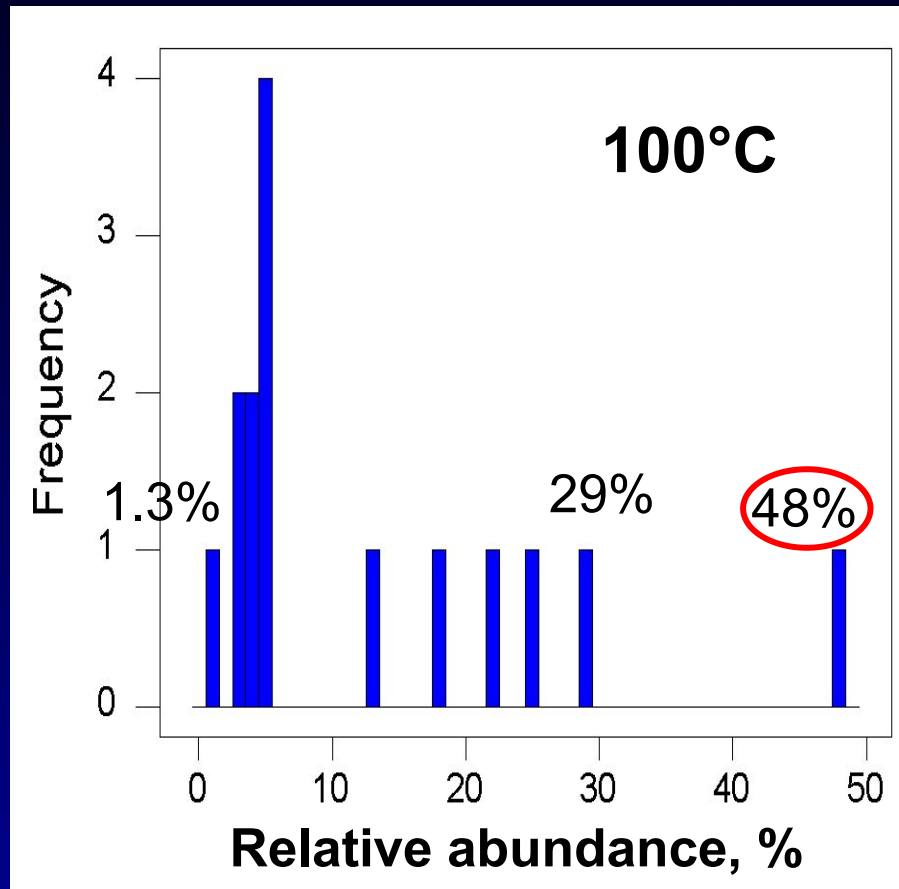
What happens to partial pressure of water vapor and RH as package is cooled below 100°C? Dew?

- Can assume water vapor behaves as an ideal gas until RH rises to 100%.
 - If 5000 ppm_v (0.005 atm) at 100°C, partial pressure will be $0.005 \times (273/373) = 0.0037$ atm at 0°C.
- Partial pressure drops due to surface *adsorption*.
 - This effect most significant for very small internal volumes.
- **The biggies:**
 - Saturated vapor pressure drops exponentially.
 - Partial pressure of water vapor drops due to polymer *absorption*.

1018 RGA : Do We Have a Problem?



- Wet fielded devices found: RA 2.5 to 100 X 1018 limit.
- Each contains 1.5 mg epoxy – enough to make a difference?



What to do?

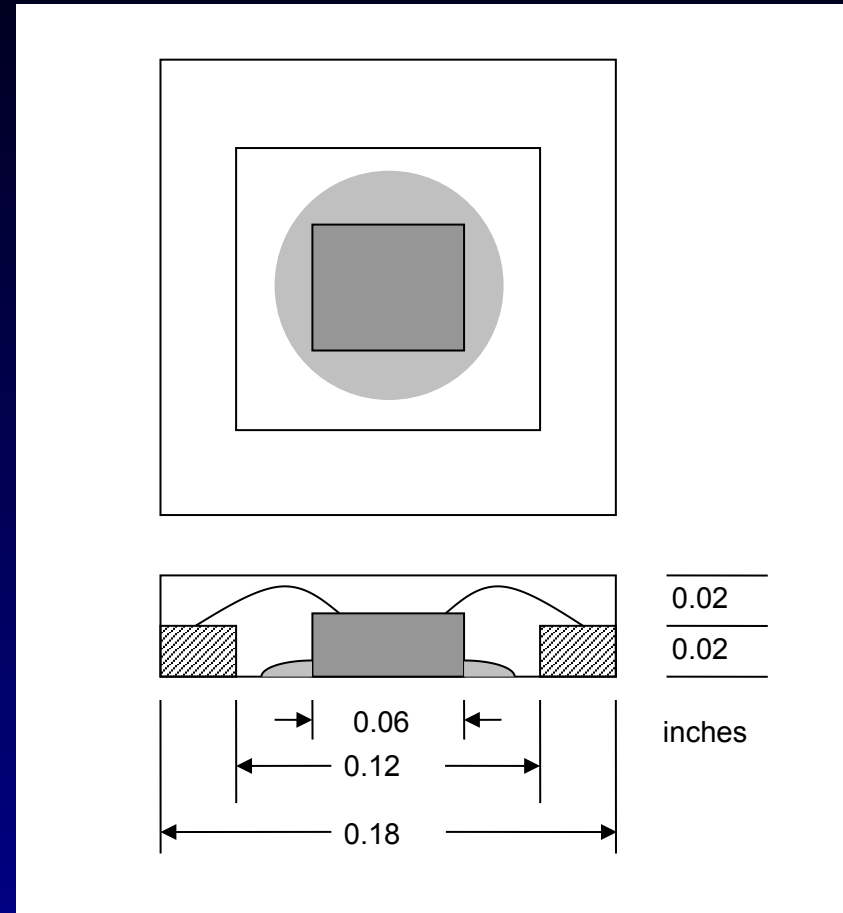


- **A lot of money at stake.**
- **Device used in a missile.**
 - Stored at 13°C.
 - Short service life.
- **Risk of doing nothing?**
- **How useful is intuition?**

Package Details and Assumptions



- Cavity volume $1.4 \times 10^{-2} \text{ cm}^3$
- Epoxy mass 1.5 mg
- Sealing temp 280°C
- Consider *absorption* (in), neglect *adsorption* (on)



Effect of polymers



- Polymers serve as *source* upon heating, *sink* upon cooling.
 - They contain a significant mass of water at 100°C.
 - Water desorbs (comes out) as temp rises, absorbs as it drops.
 - Can assume water absorbs linearly with RH, *indep. of temp* (see last slide), 1% by mass at 100% RH.
- Will show: Water partial press. @ RT may be << than @ 100°C!
 - Temporary high moisture level if heated pkg is quenched, since re-absorption takes time.
- What if service environment doesn't involve rapid cooling?

1018 moisture level may drastically overstate service moisture level



Wrongly predict a corrosion risk (false alarm).



Bad decision.

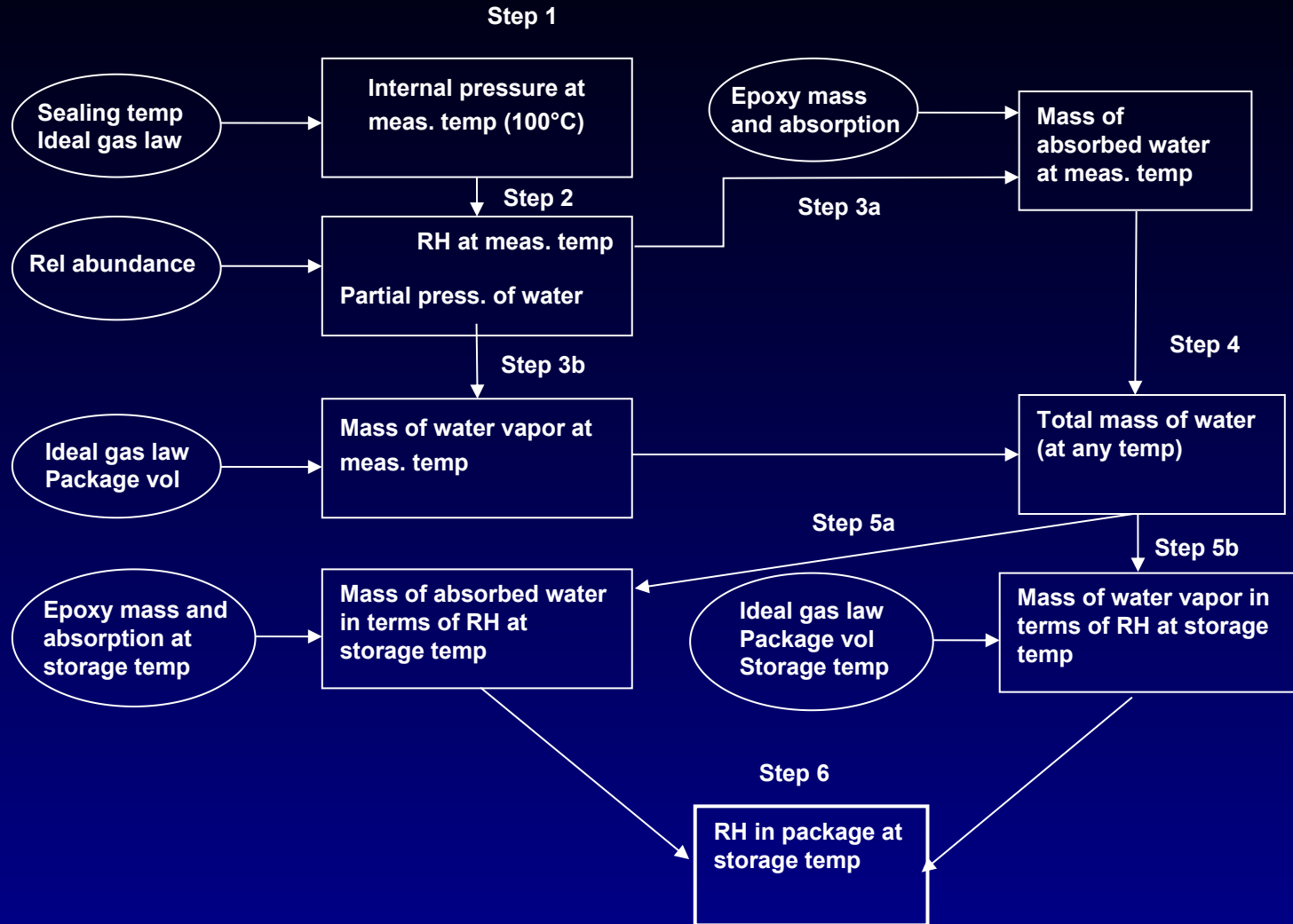
Challenge: Show that RH is Low



Approach:

- **Use given info plus laws of physics to calculate RH.**
- **Support calculations by**
 - Measuring moisture level at cooler temperatures.
 - Conducting accelerated life tests.
 - Monitoring long-term for corrosion.

Calculation Strategy: No unfamiliar equations!



Step 1: Internal pressure



- Pressure is 1 atm at sealing temperature (553K).
- By ideal gas law, pressure at meas. temp is

$$1 \text{ atm} \times \frac{373}{553} = 0.67 \text{ atm}$$

- **Corroboration:**
 - Measured (RGA): 0.63 atm.

Step 2: Partial pressure and RH at *measurement* temp (100°C)



$$\begin{aligned}\text{Partial pressure} &= \text{Rel. abundance} \times \text{Total pressure} \\ &= 0.48 \times 0.67 = 0.32 \text{ atm (worst case)}\end{aligned}$$

$$\text{RH} = \text{Partial press.} \div \text{Sat. vapor press.} = 32\%$$

Calculated dew point is 71°C.

Actual dew point < calculated, because of polymer absorption

Slower cooling → lower DP

Step 3: Mass of water vapor and absorbed water at *measurement* temp (100°C)



Press, temp, RH vary; total mass is invariant.

$$\text{Vapor mass} = \frac{pV}{RT} \times \text{mol. wt.} \Rightarrow 2.6 \mu\text{g vapor}$$

$$\text{Absorbed mass} = 1\% \times 1.5 \text{ mg} \times \text{RH} = 15 \mu\text{g} \times \text{RH}$$

$$\text{For } 48\% \text{ RA, } 32\% \text{ RH} \Rightarrow 4.8 \mu\text{g absorbed}$$

Step 4:

$$\text{Total mass} = \text{vapor} + \text{abs} = 7.4 \mu\text{g}$$

Step 5: Mass of absorbed water and water vapor at *storage* temp



In terms of RH:

Vapor mass = total - absorbed

Absorbed mass = $15 \mu\text{g} \times \text{RH}$

Vapor mass = $m_{\text{sat}} \times \text{RH} = \frac{p_{\text{sat}} V}{RT} \times \text{mol. wt.} \times \text{RH}$

Step 6: Calculate storage-temp RH from masses of vapor and abs. water



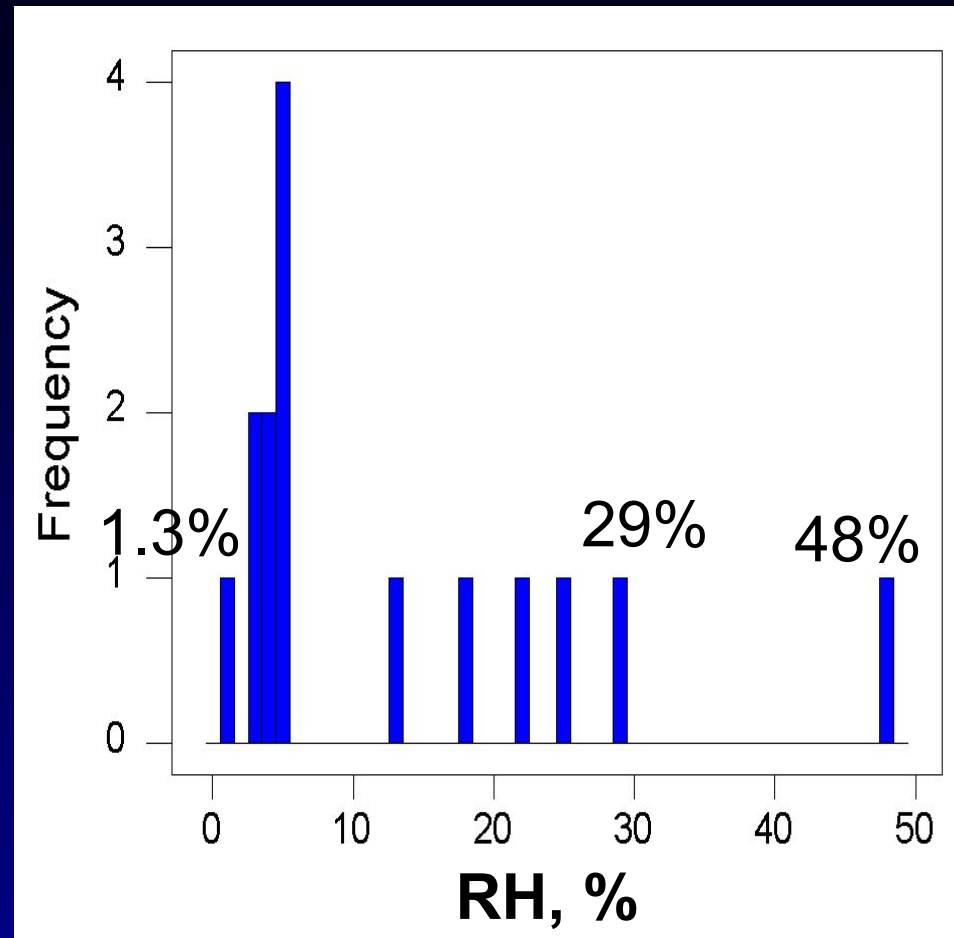
Storage-temp RH \approx Meas. RA (for this kind of pkg.)

Result not sensitive to storage temp

Recall (Step 2) that RGA RH = 0.67 X RA

Storage-temp RH not high after all

+ Operating RH will be lower due to device heating



What about other cases?



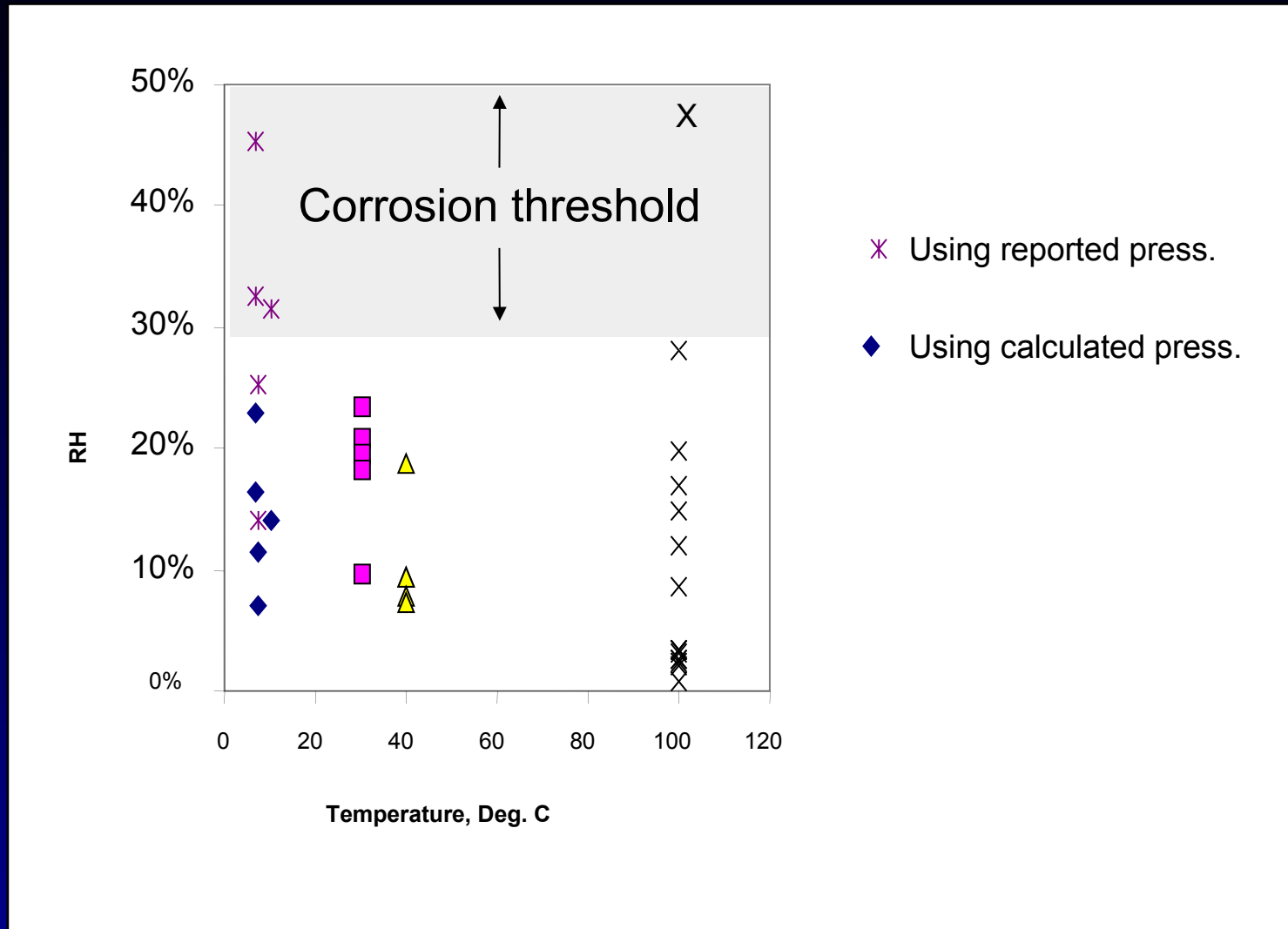
1. Package with no plastics, room air inside

- RH 50% at room temp, dew point 10°C
- Bad if conditions involve operating below room temp

2. Package with lots of plastics, room air inside

- RH 50% at room temp, RH 50% above and below
- Comparable to case considered
- Bad if operating conditions frequently involve heating followed by rapid cooling

Corroboration: Low-temp RGA



Corroboration: Accelerated and long-term testing



- **Open packages in autoclave: 130°C/85% RH**
 - Test and examine up to 96 hours
 - Equivalent to ten years using 0.9 eV and (RH)³ accel. factor.
- **Sealed packages in oven: 130°C**
 - Test up to 592 hours
 - Equivalent to ten years using 0.9 eV.
- **Sealed packages in room**
 - Test up to a year, open and examine after one year
- **Result: no corrosion, full functionality**

What is needed for reliability?



- **Don't want liquid water, or even prolonged high RH**
 - Rapid cooling allows high RH if polymers are present
 - Can test using Method 1031
 1. Heat
 2. Cool
 3. Warm to make chip coolest surface
 4. Apply bias
 5. Repeat several times
- **Liquid water possible at RH < 100%**
 - Can condense in cracks (theoretical)
 - Can condense at ionic impurities
 - NaCl ~75%

Conclusion



- **Method 1018 RGA relative abundance results may drastically overstate the amount of water vapor present under real-world conditions**
 - Fails to present moisture level in terms of partial pressure
 - Fails to distinguish between RA and RH
 - Can lead to bad decisions
- **Straightforward calculation of RH shows how to determine the corrosion risk**
- **Results corroborated by RGA, accelerated testing, and long-term monitoring**

Calculation of water in polymers



- Concentration of water in polymers can be expressed as dimensionless product of three terms:

$$c_w = RH \times p_{\text{sat}} \times S$$

- Saturation vapor pressure p_{sat} increases exponentially with temp, energy factor is enthalpy of vaporization ΔH_v .
- Absorptivity S decreases exponentially with temp, energy factor is solution enthalpy ΔH_s .
- For fixed RH, exp. factor varies as the sum of these enthalpies (difference in their absolute values).
- Since $\Delta H_v \approx -\Delta H_s$, **c_w is roughly temperature invariant.**