Thermal Profiles –
Why Getting them Right is Important

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given at
American Competitive Institute
Lead Free Workshop
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www.btu.com

BTU

Presentation Outline

- Recipe vs. Profile
- Material Properties
- Why profiles are shaped like they are.
- Obtaining profiles
    - TC Accuracy
    - Profilers
    - Test vehicles
- Process Window – Eutectic vs. Lead Free
- Heat transfer
- Oven Control

Profile vs. Recipe

- **Profile** is the targeted thermal process

- **Recipe** is the oven/furnace settings to obtain the profile

SMT Profile / Thermal Target

•Peak Temperature	• Max/Min ºC
•Time to Peak	• Minutes – Max
•Time Over Liquidus (TAL)	• Range - Sec
•Soak time & temperature (FAT)	• Ranges
•Heating-Cooling rates	• ºC/Sec
•Atmosphere	• Specification PPM O_2

Typical Solder Reflow Profile Target

- Peak temperature = 240 ± 10 ºC
- Time to peak = 3 minutes Max
- TAL = 60 ± 15 seconds
- Soak = 160 to 190ºC for 60 to 90 sec
- Ramps =
  - +2.0 ºC/sec Max
  - -1.5 ºC/sec Min
- Atmosphere = Oxygen 50 PPM in N_2

7 items

Plus atmosphere

Recipe

Oven or Furnace Settings

- •Zone set points
- •Belt speed
- •Static pressure
- •Gas flow

3 Control Knobs

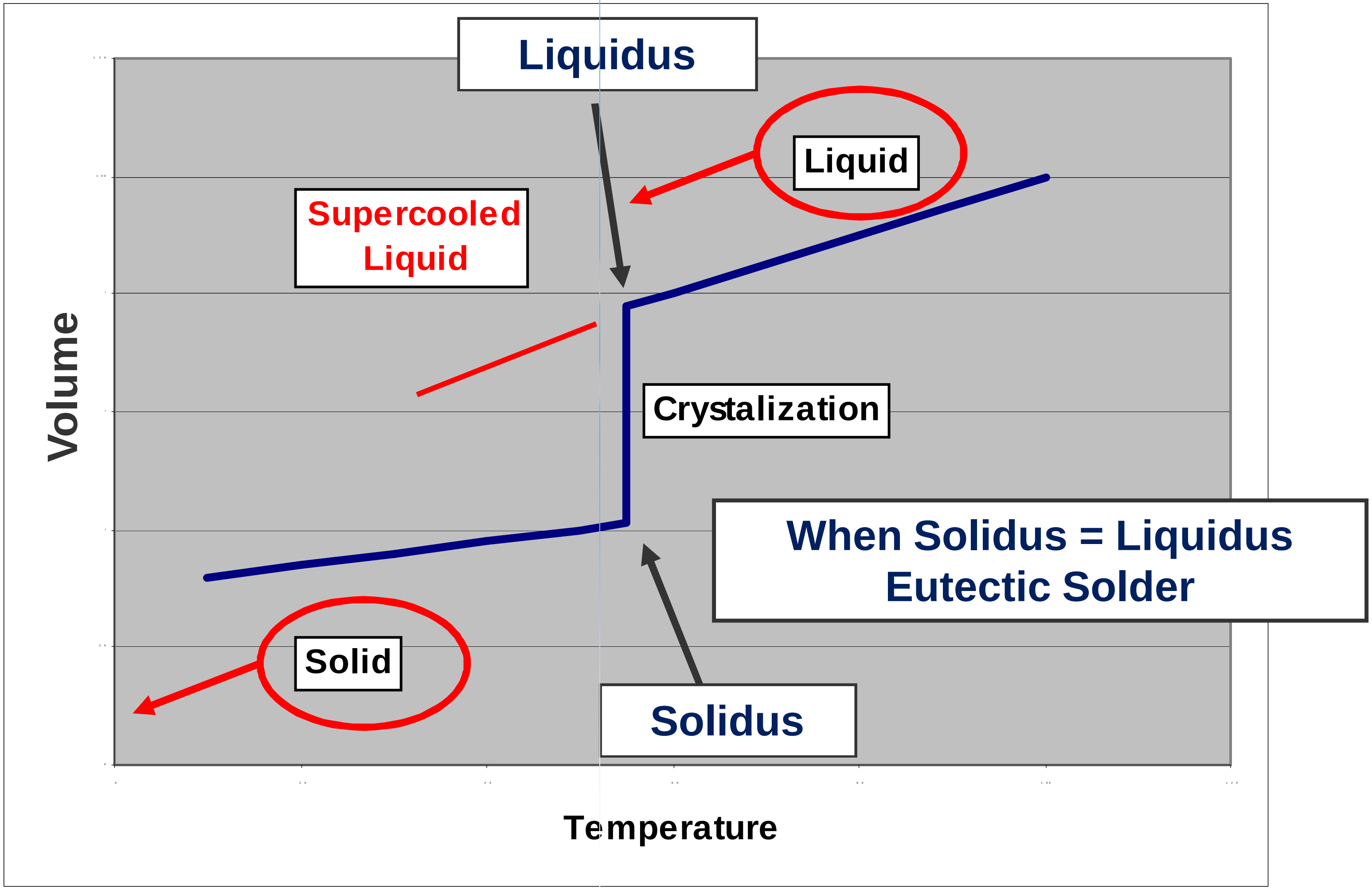
Plus atmosphere

Important factors for thermal profiles?

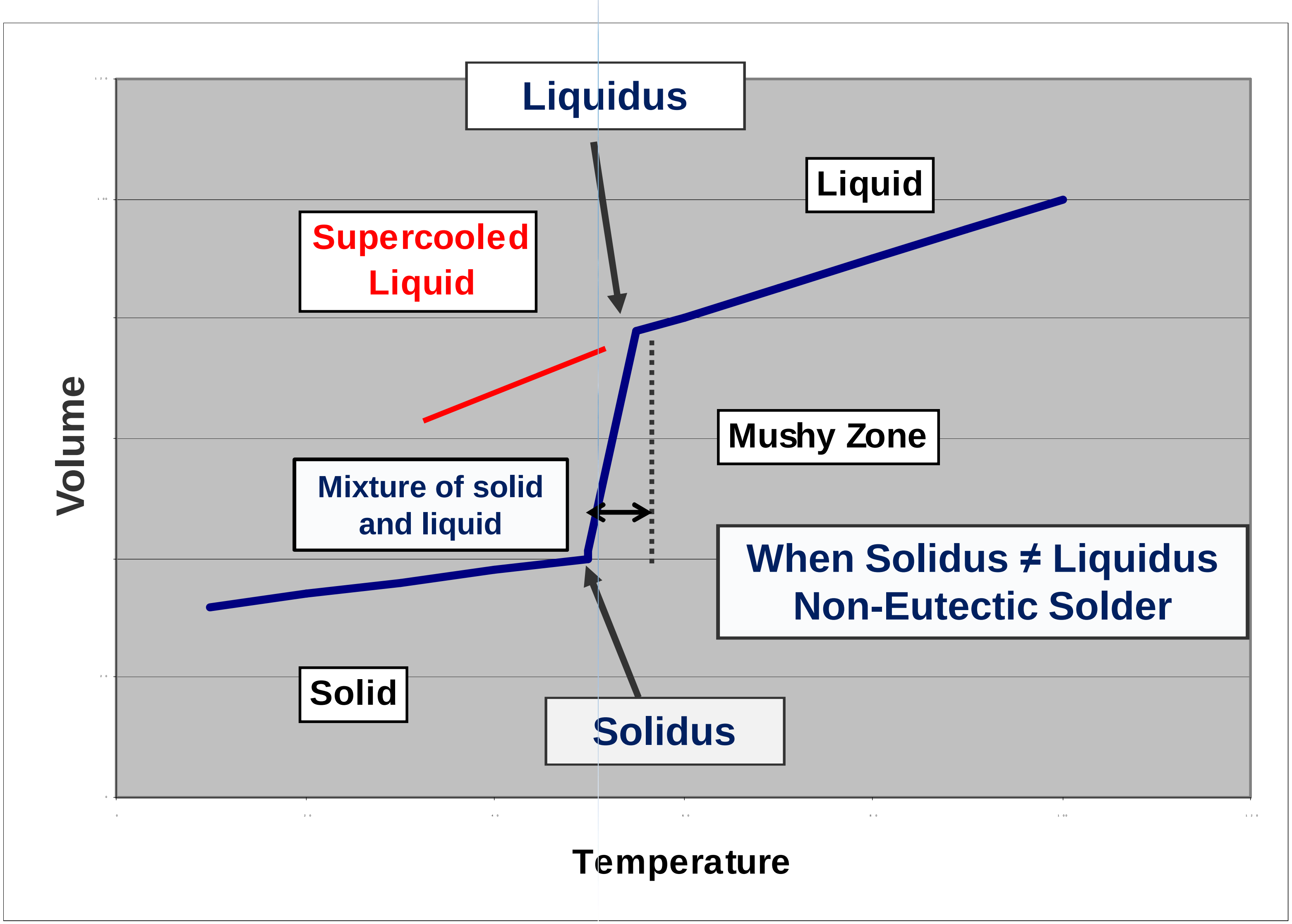
Time, temperature, atmosphere required to process the solder

- **Solder attributes**
  - Liquidus
  - Solidus
  - Flow / Viscosity
  - Dissolution Rate
  - Oxidation
  - Crystallization
- **Components or support structure**
  - Critical temperatures

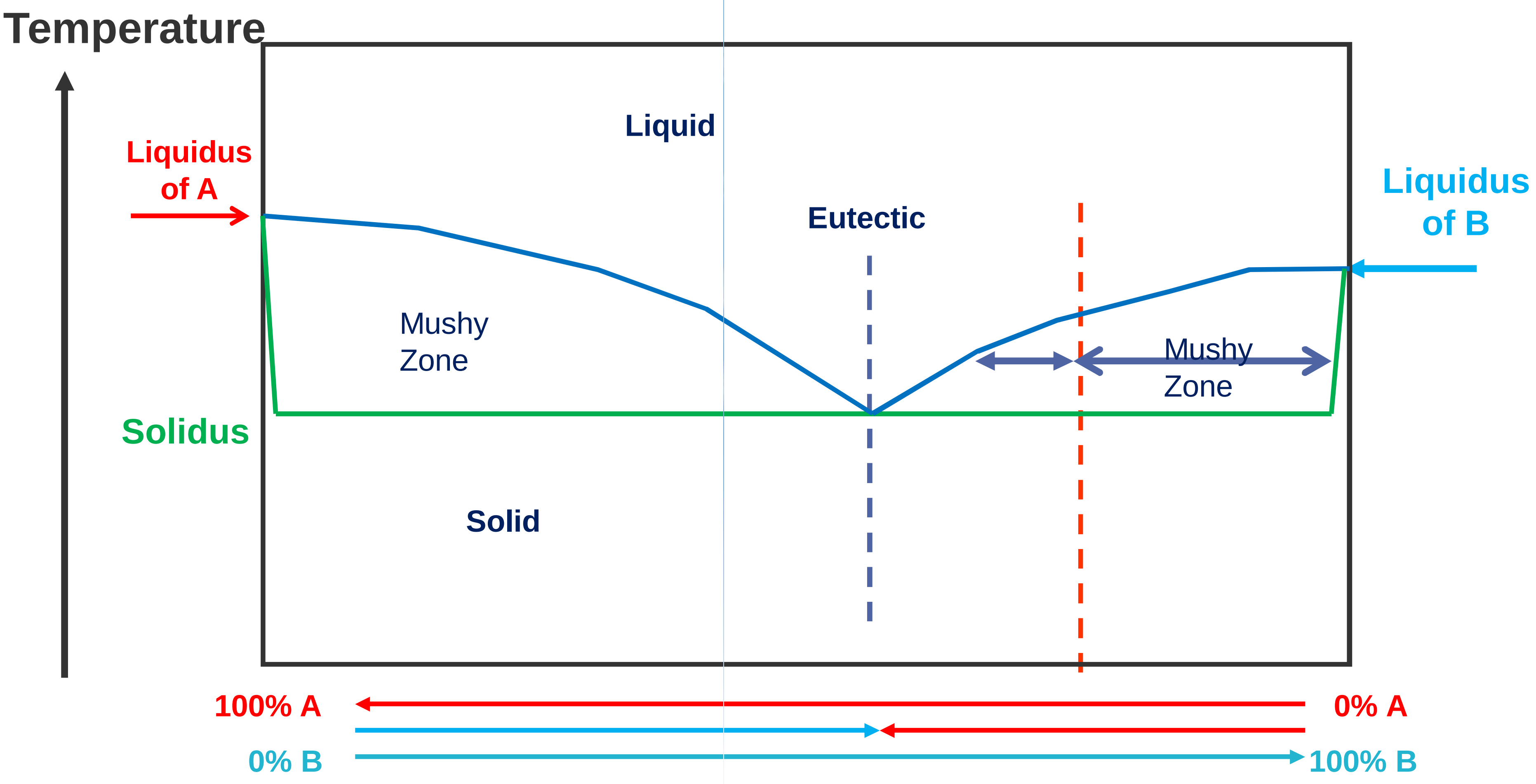
Material Phase Changes



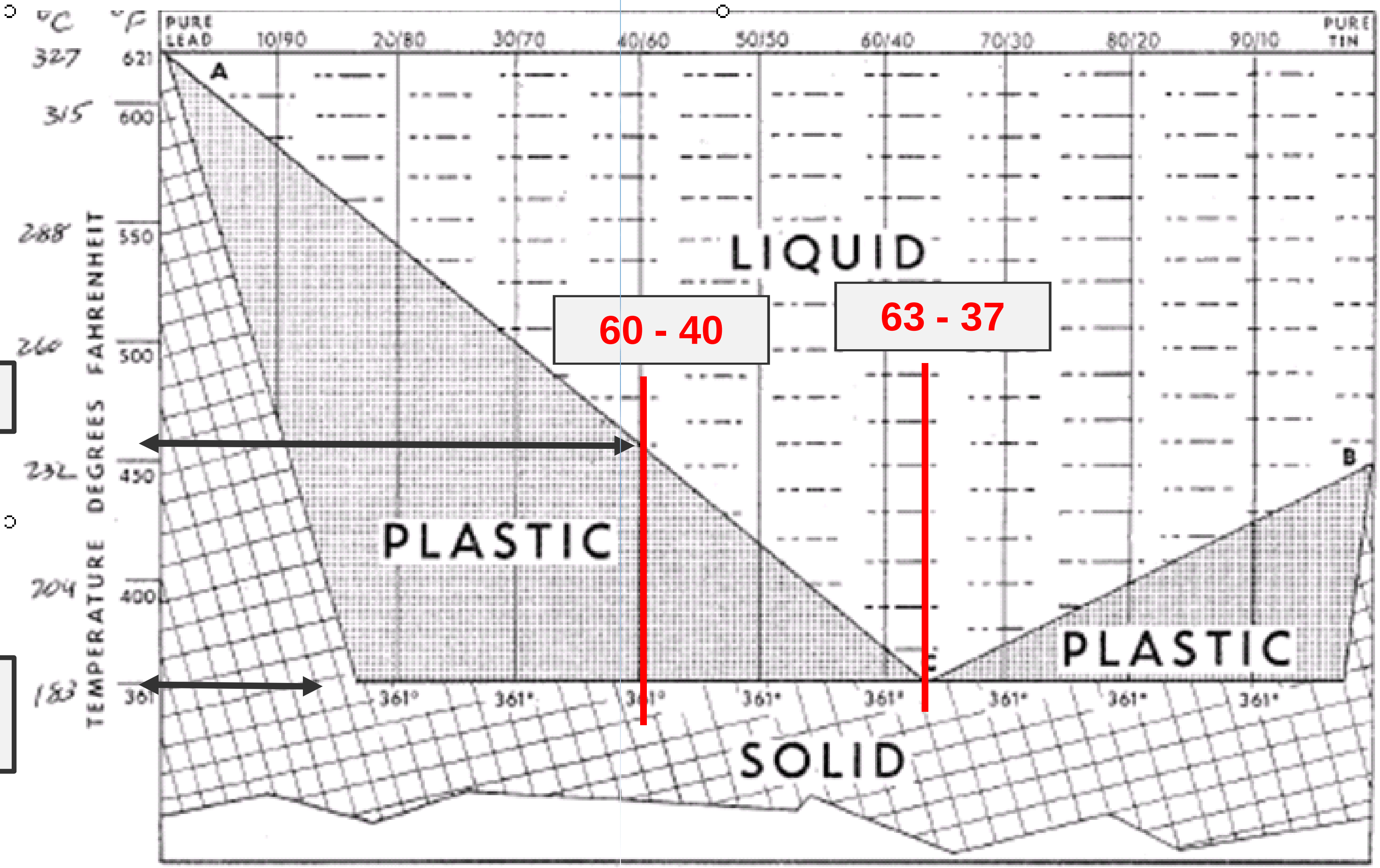
Material Phase Changes



2 Component Phase Diagram



Tin/Lead Solder Phase Diagram



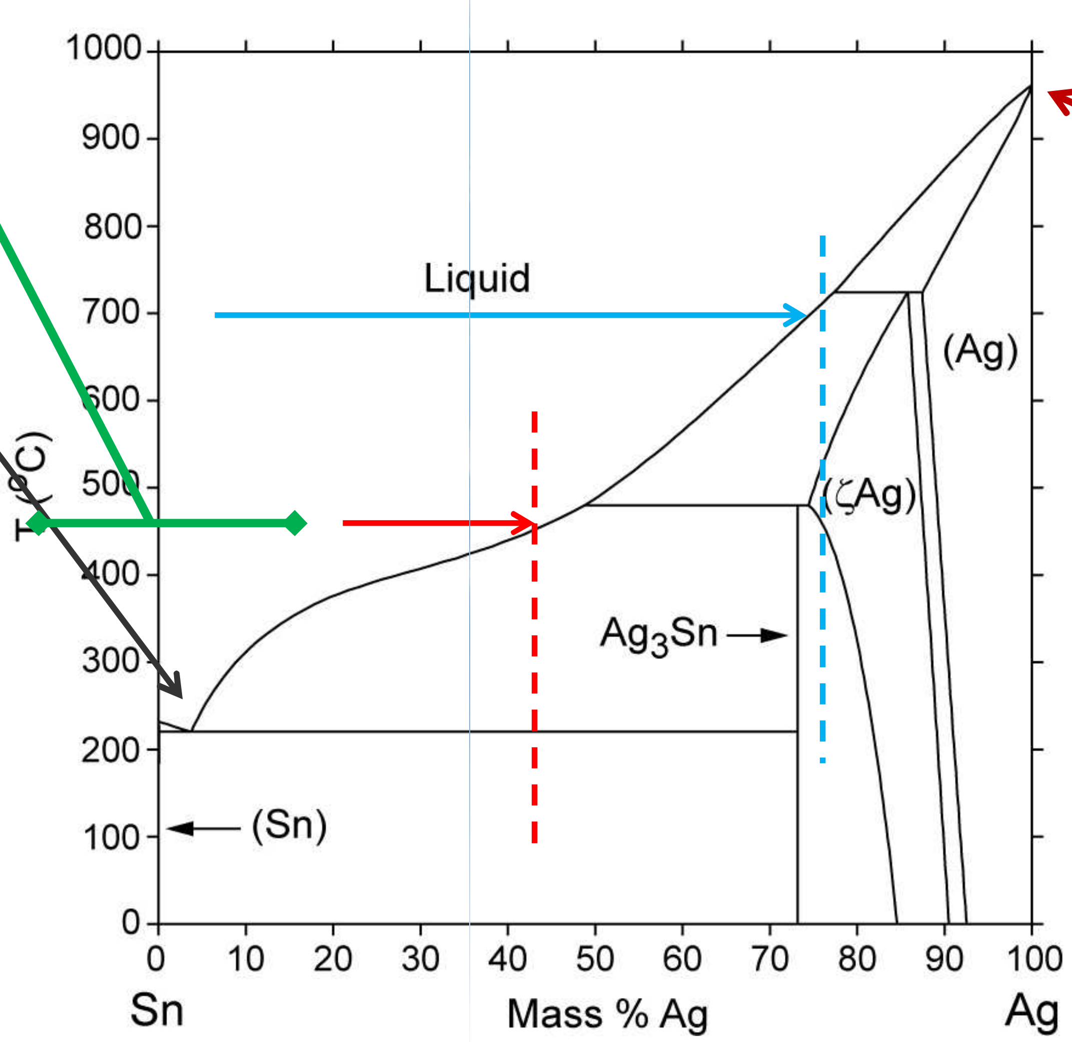
60 - 40

63 - 37

Liquidus

Solidus
183 ºC

Tin/Silver Solder Phase Diagram



Normal silver solders

Eutectic ?

Melting point of silver

**source: http://www.metallurgy.nist.gov/phase/solder/solder.html*

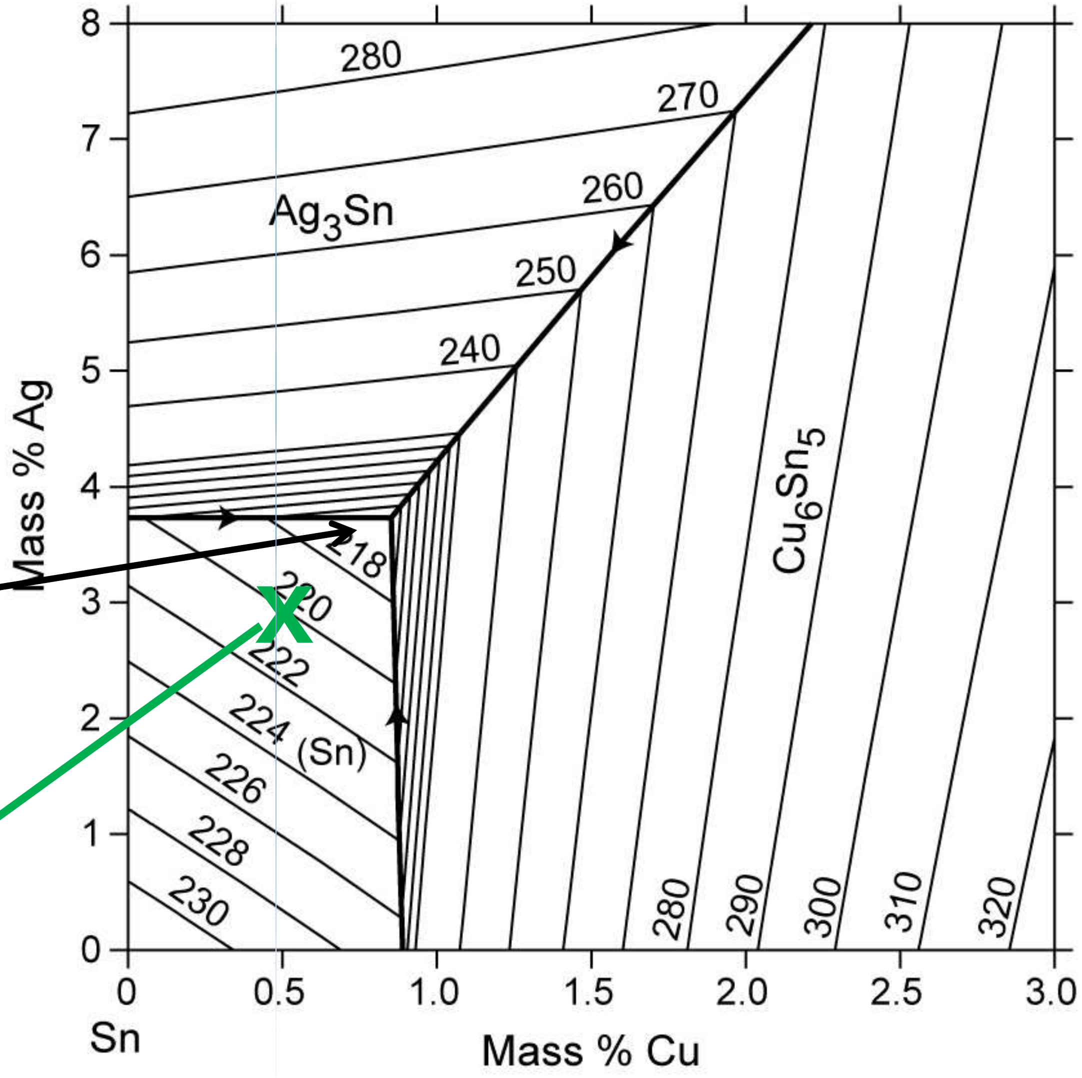
Tin-Silver-Copper (lead free solder) Phase Diagram

SAC

Sn – Tin

Ag – Silver

Cu - Copper



Eutectic 217 ºC

SAC 305

221 ºC

source: http://www.metallurgy.nist.gov/phase/solder/solder.html

Flux

Derived from **Latin** *fluxus* meaning “flow”

- **Purpose**
  - Carrier for solder
    - Solvent and Active Ingredient
    - Correct flow characteristics for screen printing?
      - Dilatant – thickens with shear
      - Thixotropic – Thins with shear
  - Removes Oxidation from metals
    - Acidic & Corrosive
    - Reducing
  - Seals out air during reflow
    - Ability to remain on the board during reflow
  - Improves wetting characteristics of the solder

Reflow Solder Flux

- **Types** **as defined by J-STD-004**
  - Rosin (RO)
  - Resin (RE)
  - Organic (OR)
  - Inorganic (IN)

Flux is corrosive - the parts have to be cleaned after soldering to prevent damage unless it is no-clean.

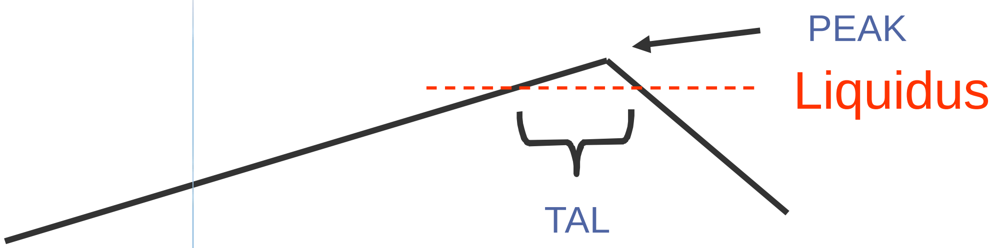
Atmosphere can be flux

Hydrogen

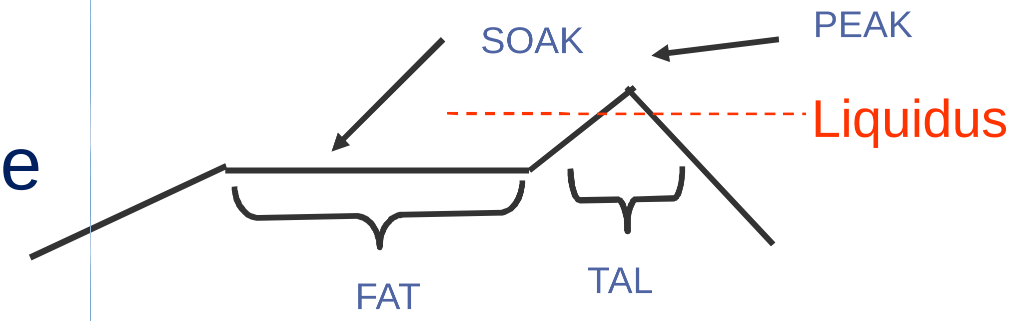
Hydrogen - Nitrogen

Thermal Profiles

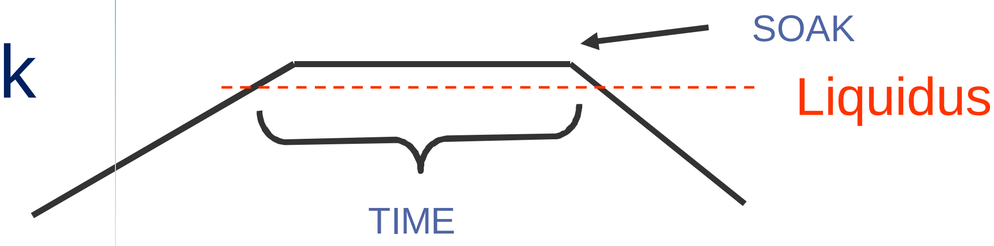
Ramp - Spike



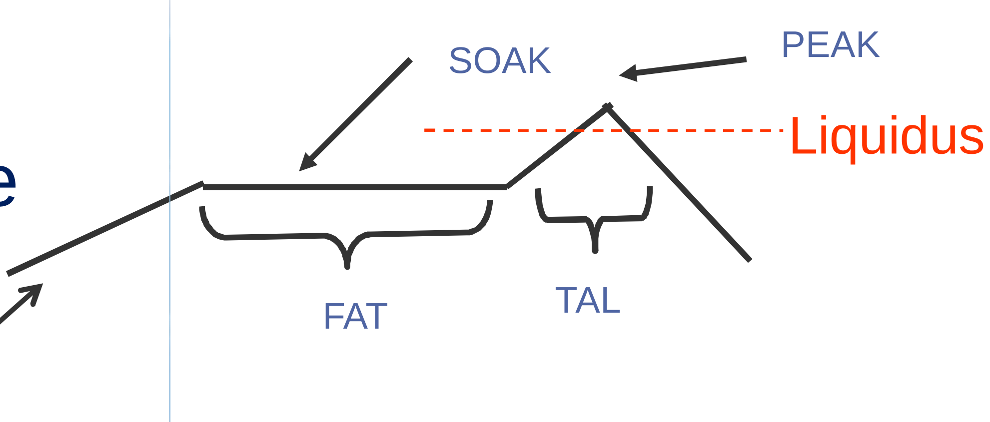
Ramp – Soak – Spike



Ramp – Soak



Ramp – Soak - Spike



Ramp – Soak – Spike

Initial Heating Ramp

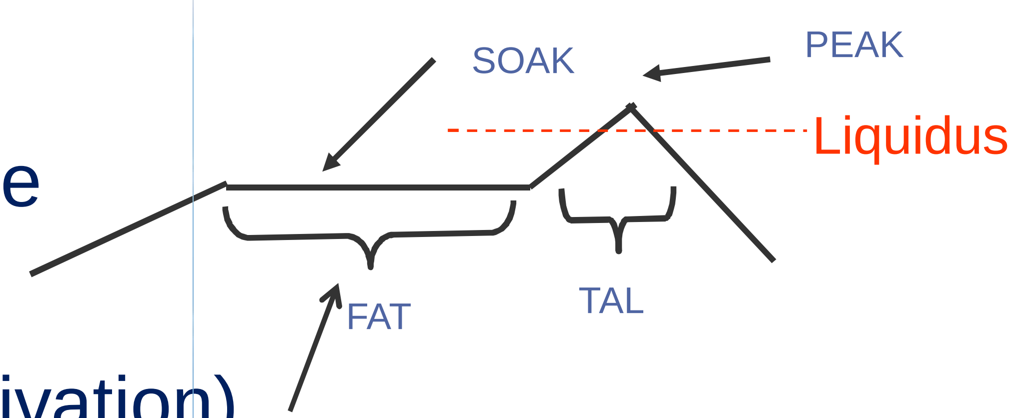
Reason - Increase the product temperature
Given as ºC per second

If too slow – waste time - $$$

If too fast
- Flux solvents outgas and parts move
- Small parts tombstone - stand on end
- Thermal shock can break parts
- Center of BGA’s don’t get heat

Ramp – Soak - Spike

Ramp – Soak – Spike



Soak aka FAT (flux activation)

Reason – Gives the flux time to clean the metal

Allows the temperatures to equalize before the reflow spike

Given as temperature and time range

If the time is too long or temp too high

The flux disappears before reflow is completed

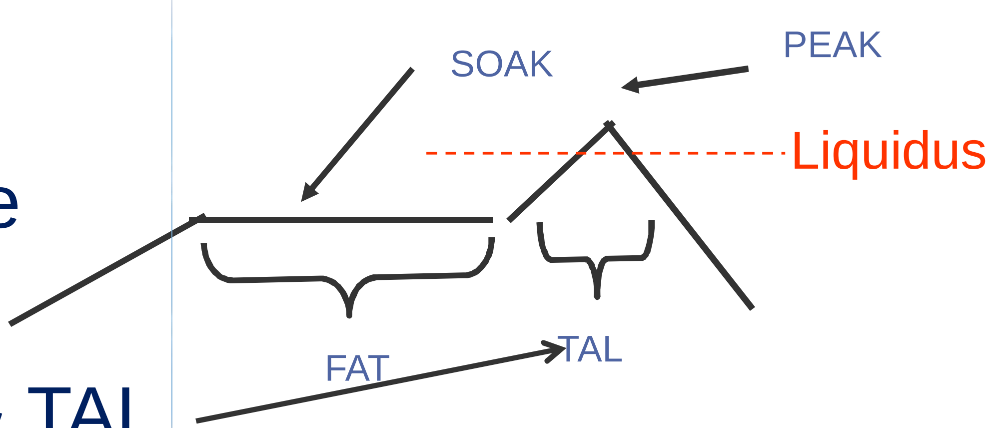
The parts oxidize and you get poor joints

If too fast or temp too low

There is not enough energy for the flux to work

There are large delta T’s at peak

Ramp – Soak - Spike



Ramp – Soak – Spike

Peak & TAL

Reason – Melts the solder

Time allows the liquid solder to react and form joints

Given as temperature range and time

If the time is too long or temp too high

The flux disappears before reflow is completed

The parts oxidize and you get poor joints

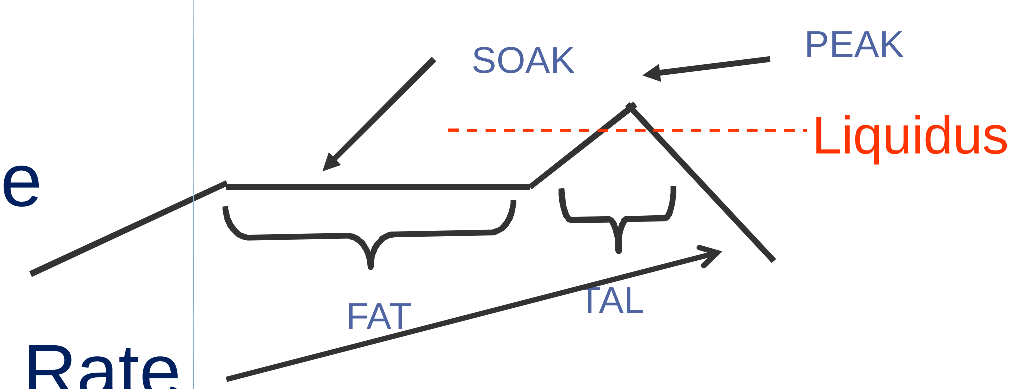
Can develop unwanted intermetallics

If too fast or temp too low

The solder down not have enough time to melt and flow

There are large delta T's at peak

Ramp – Soak - Spike



Ramp – Soak – Spike

Cooling Rate

Reason – Gets the product to room temperature
Given as ºC per second

If too fast there is stress in joints of big parts

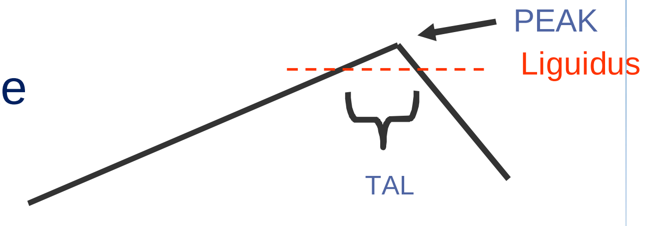
If too slow waste time
Can extend the TAL and develop bad intermetallics

Lead Free (SAC)

Concerns about maintaining the flux with a peak temperature of 240 vs. the 220 ºC needed for eutectic solder

Initially endeavored to shorten the total process time so a Ramp – Spike profile was used

Ramp - Spike

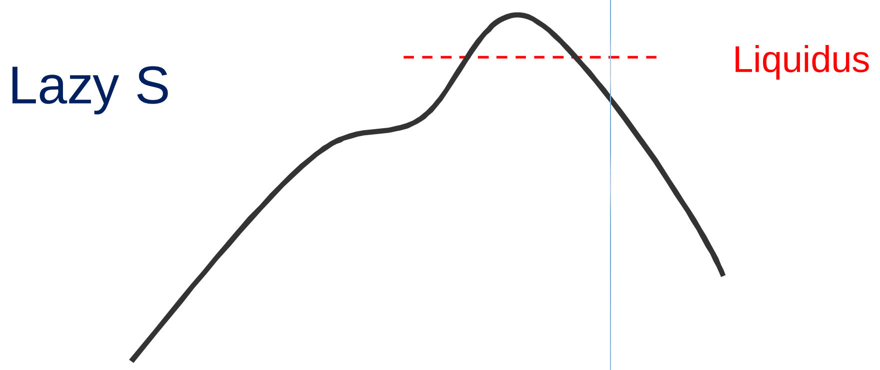


There was competition between minimizing the process time and slow ramps.

Nitrogen was used to make the joints look better and help extend the time flux remained

Lead Free (SAC)

Fluxes have been modified and we now have now moved to the lazy S profile with a short FAT



Nitrogen is only used in special cases where the solder joint has to look shiny

SAC Cooling Rates

SAC cooling rate became an issue when someone identified that SAC had less mechanical strength than eutectic solder.

A paper was published that said high cooling rates increased the strength due to smaller grains so people wanted 6-10º/sec and more.

At the same time people with big BGA's wanted cooling rates of 0.5 ºC/sec because thermal gradients caused the balls to crack when the cooling was too fast .

We later learned that the small grains were obtained with 100+ºC/sec cooling rates

Today we are at 1-3ºC/sec for most SAC solder pastes

Outline

- Recipe vs. Profile
- Material Properties
- Why profiles are shaped like they are.
- Obtaining profiles
  - TC Accuracy
  - Profilers
  - The test vehicle
- Process Window - Eutectic vs. Lead Free
- Heat transfer
- Oven Control

How do you obtain the profiles?

Temperature Sensor &
Data Acquisition Device

Thermocouple (TC)

Thermal Process Profiler

Temperature Sensor

Thermocouples

What is a TC?

1821 Thomas Seabeck discovered that when two dissimilar metals were joined, they produced a voltage. (like a little battery)

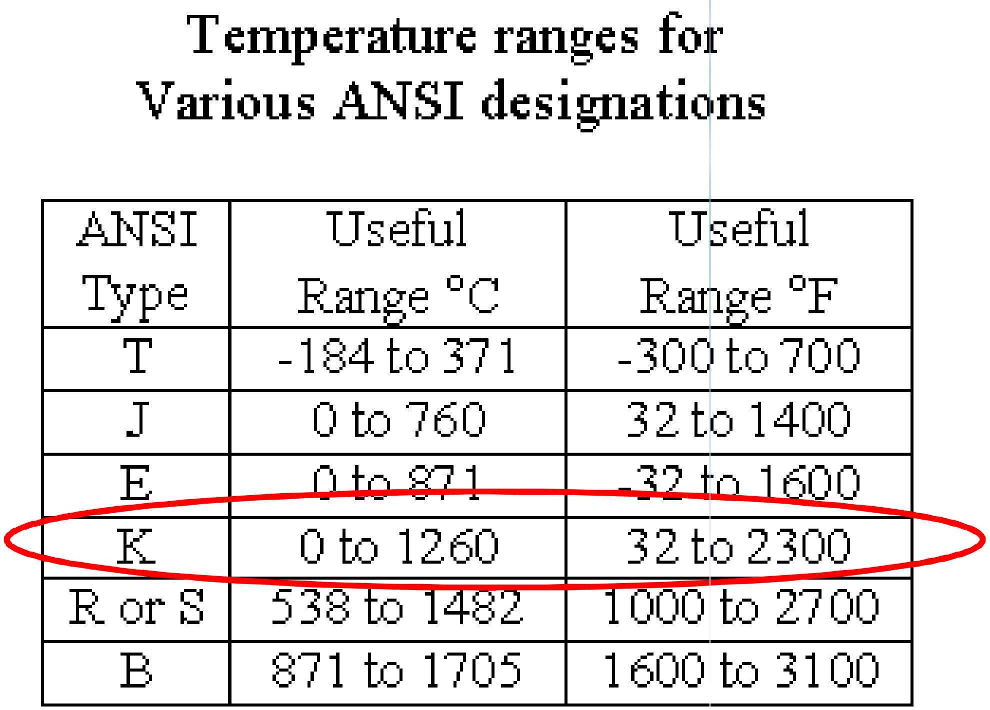
The properties of “Seabeck Voltage” that are useful to process people:

1. Voltage Varies with Temperature
2. Repeatable.

Thermocouples

Official Standards

American National Standards Institute has established designations and published voltage tables for TCs.



Temperature ranges for
Various ANSI designations

ANSI Type	Useful Range °C	Useful Range °F
T	-184 to 371	-300 to 700
J	0 to 760	32 to 1400
E	0 to 871	-32 to 1600
K	0 to 1260	32 to 2300
R or S	538 to 1482	1000 to 2700
B	871 to 1705	1600 to 3100

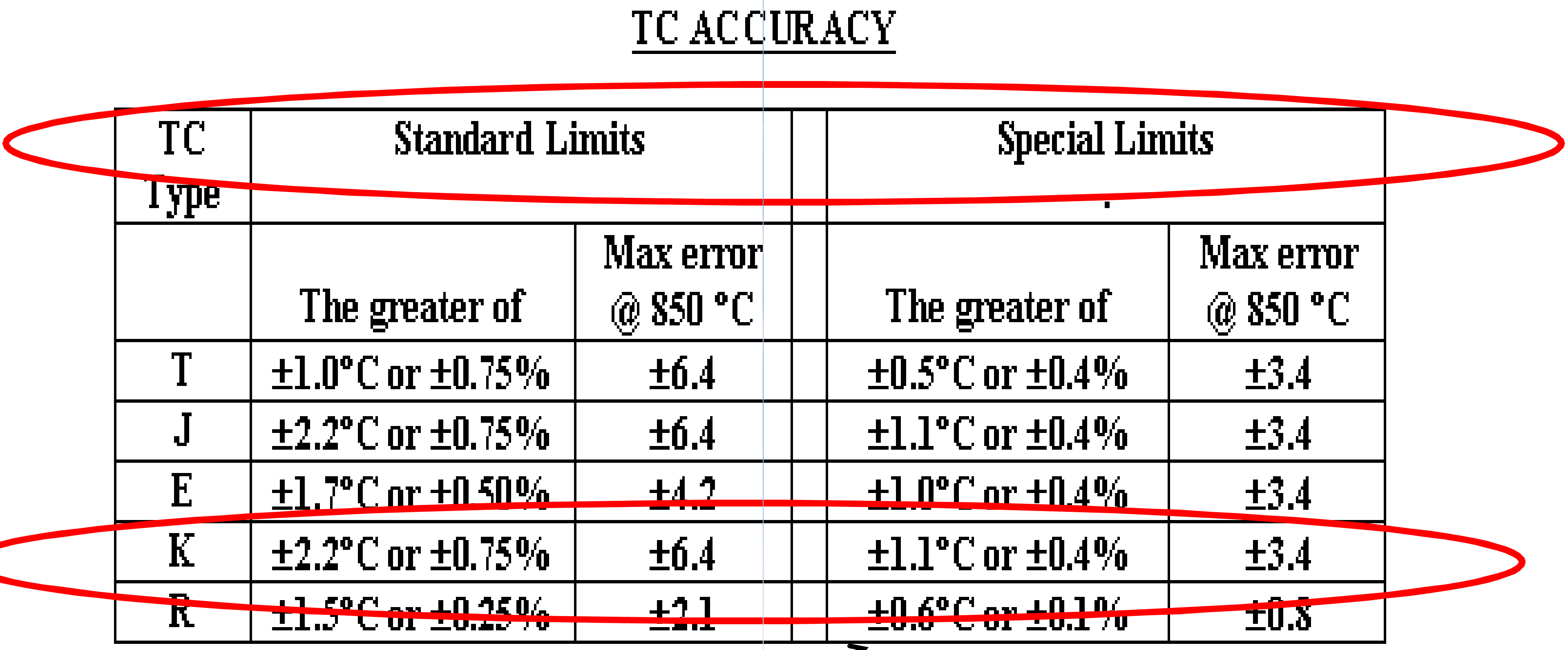
There are other that are universally used but do not have "official status"

Such as Platinel, and Type N

Nickel-Chrome
Vs
Nickel-Aluminum

Data from The Temperature Handbook,
Omega Engineering

Grades of TC Wire



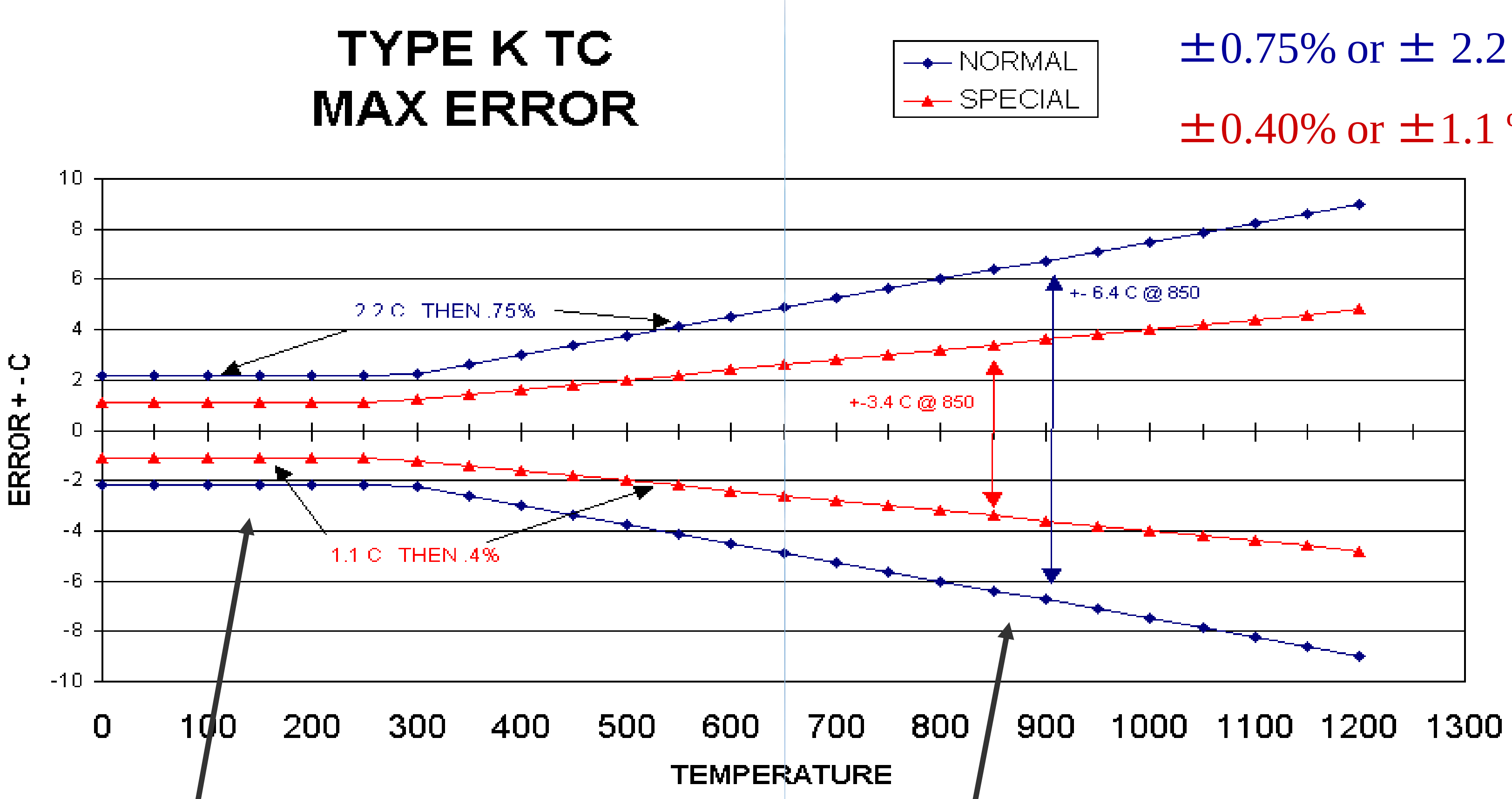
TC ACCURACY

TC Type	Standard Limits			Special Limits	
	The greater of	Max error @ 850 °C		The greater of	Max error @ 850 °C
T	±1.0°C or ±0.75%	±6.4		±0.5°C or ±0.4%	±3.4
J	±2.2°C or ±0.75%	±6.4		±1.1°C or ±0.4%	±3.4
E	±1.7°C or ±0.50%	±4.2		±1.0°C or ±0.4%	±3.4
K	±2.2°C or ±0.75%	±6.4		±1.1°C or ±0.4%	±3.4
R	±1.5°C or ±0.25%	±2.1		±0.6°C or ±0.1%	±0.8

I Want to use type R!!!

Good for 538 to 1482ºC
And they are Platinum

Type K TC Error Cone



±0.75% or ± 2.2 ºC

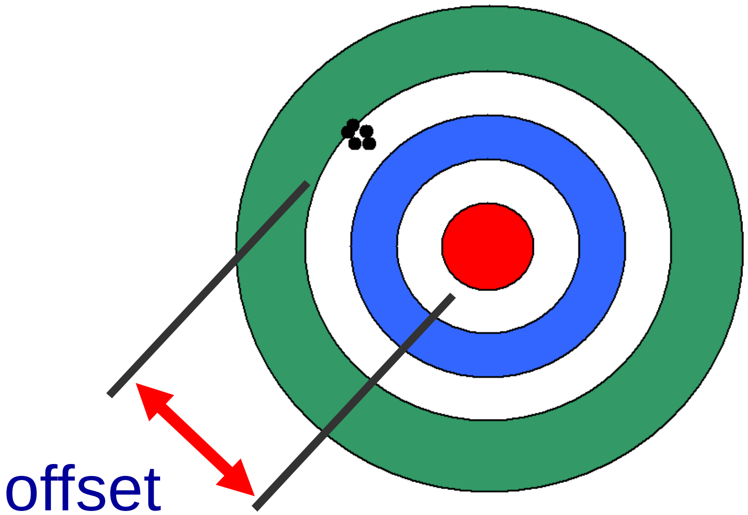
±0.40% or ±1.1 ºC

Below 300 ºC the error is ± 2.2 or 1.1 ºC

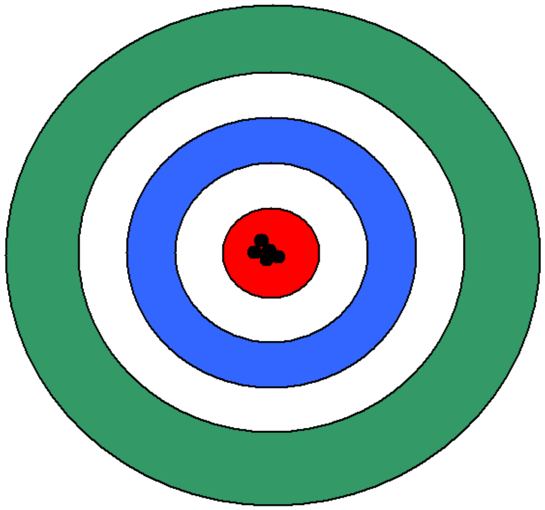
At 850ºC the error is ± 6.4 or 3.4 ºC

Accuracy vs Repeatability

- **Accuracy – the ability to hit the <u>target</u>.**
- **Repeatability – the ability to hit the <u>same place</u> each time**

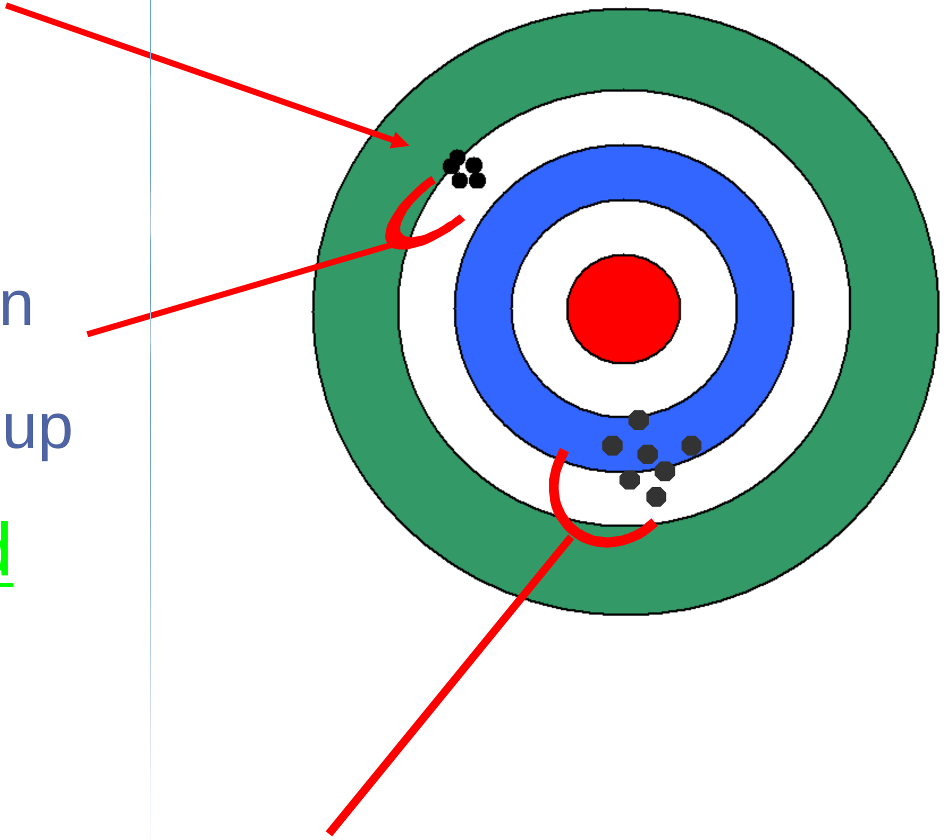


Repeatable



Repeatable and Accurate

Statistical Terms



Accuracy = Average
Where we hit

Repeatability =
Standard Deviation

Size of the shot group

Low number - Good
Narrow Spread

High number - Bad
Wide spread

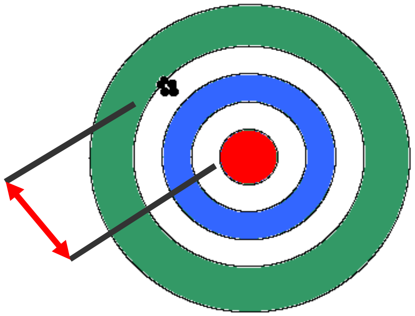
Accuracy

Certified TC Wire is Available

Cost is $75 to $100 for the first temperature and $20 to $30 for each additional point.

Certification -

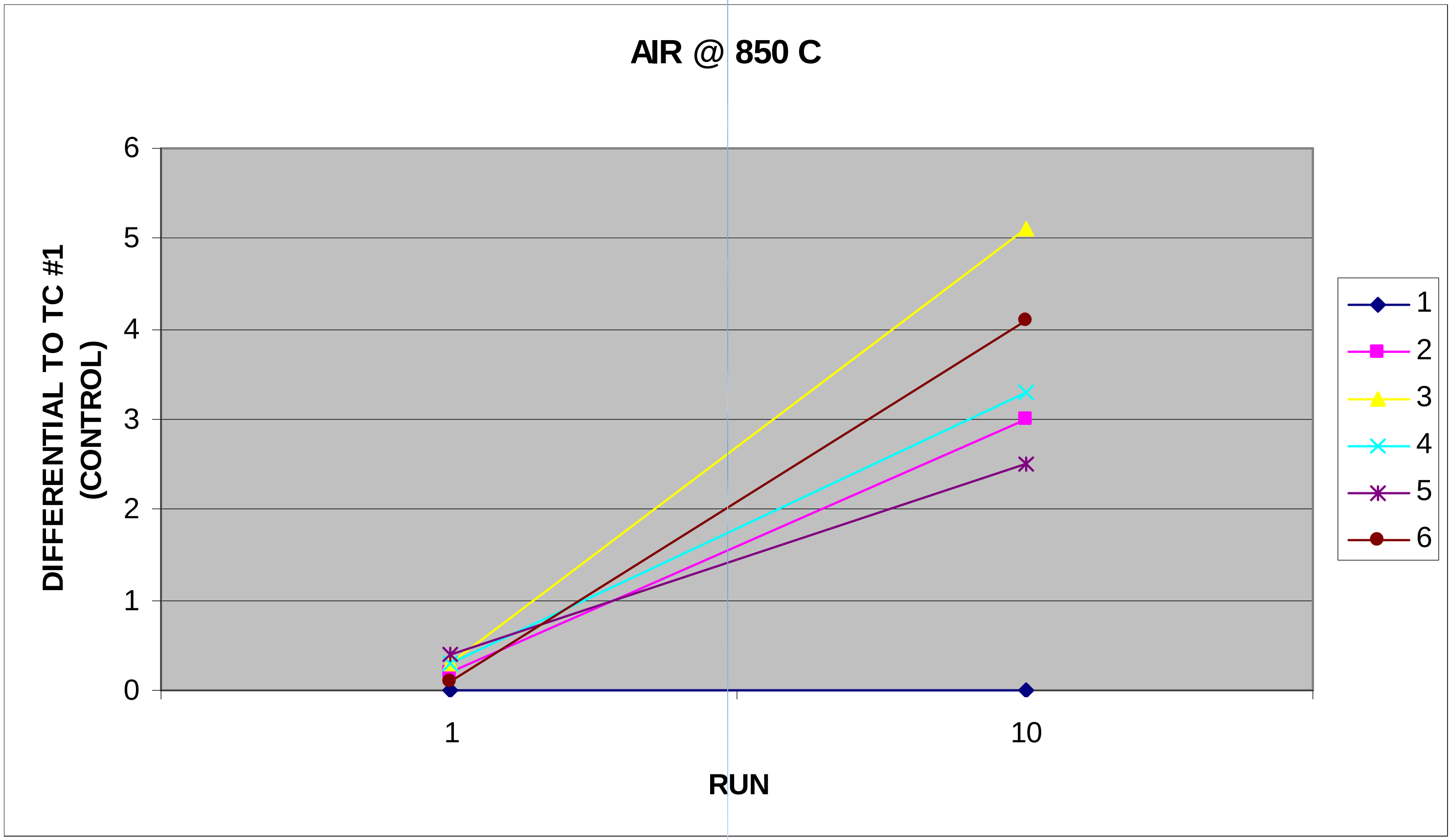
Documents the offset



at the measured temperature

****

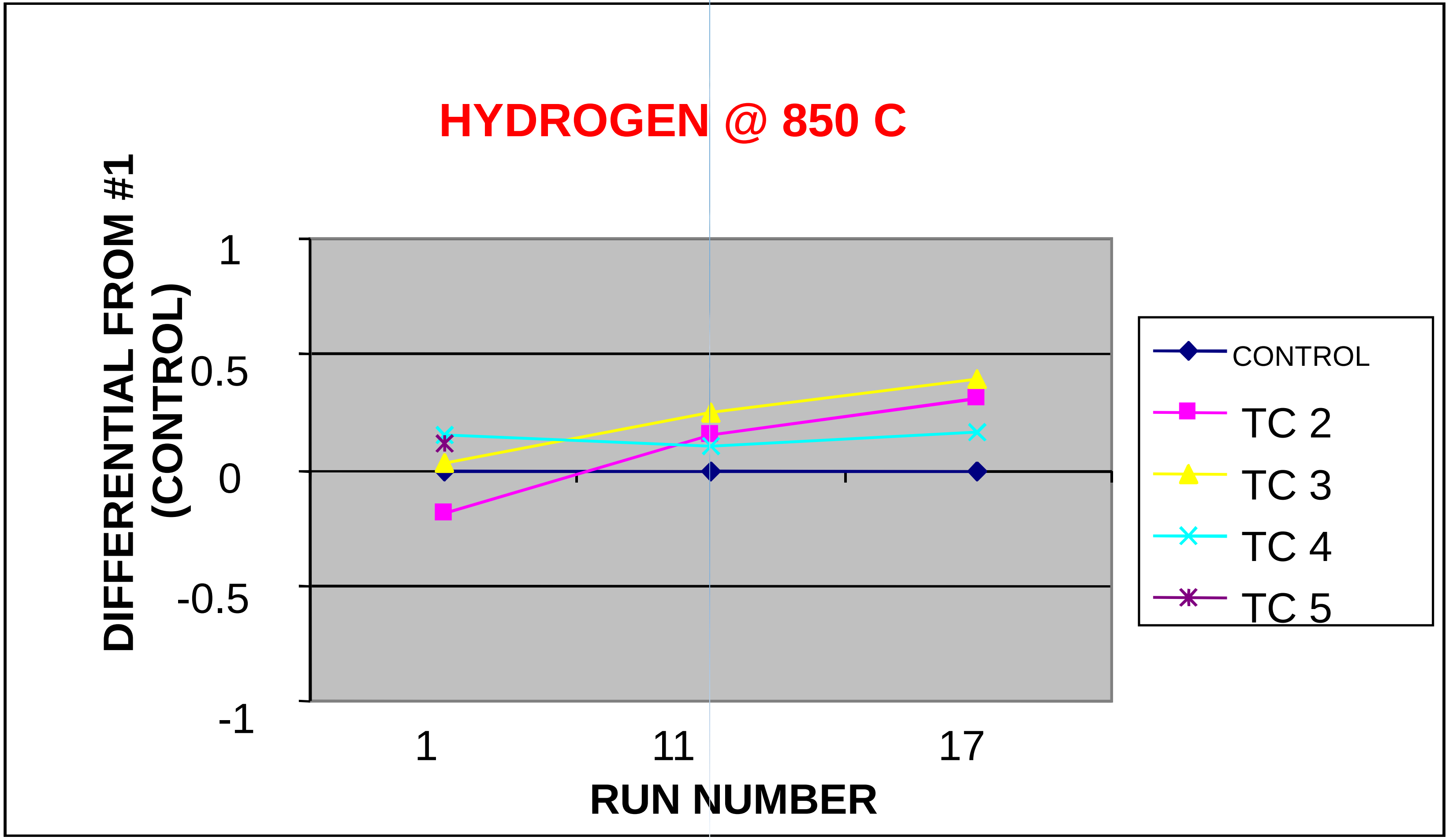
TC Ageing Type K



Control

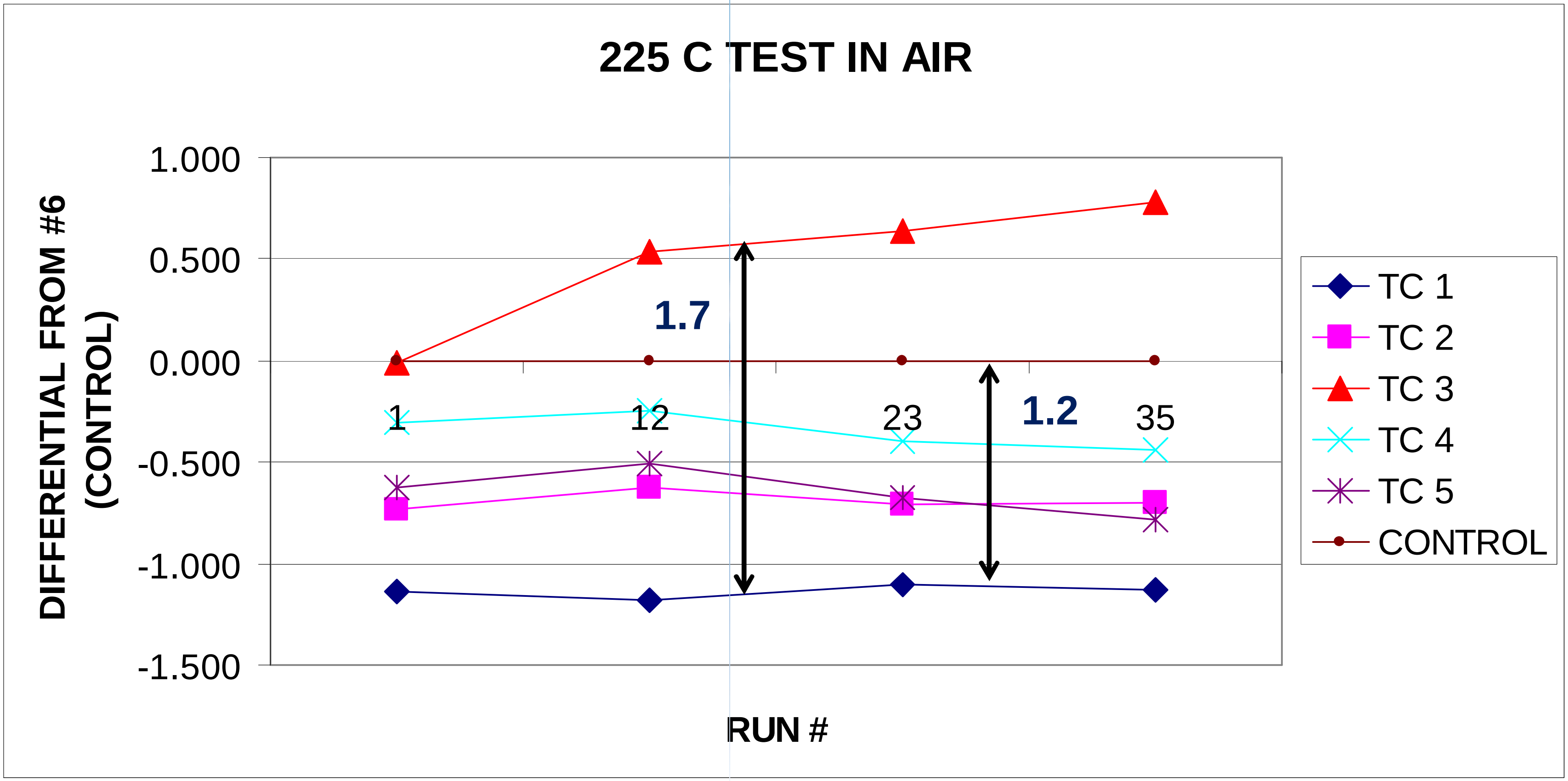
TC Ageing

Type K



TC Ageing

Type K



Thermal Process Profilers

- KIC Explorer / 2000
  - AutoFocus / Navigator
- ECD
  - Profile Planner
- DataPaq
  - Easy Oven Setup (EOS)
- Reflow oven manufacturer’s imbedded profilers

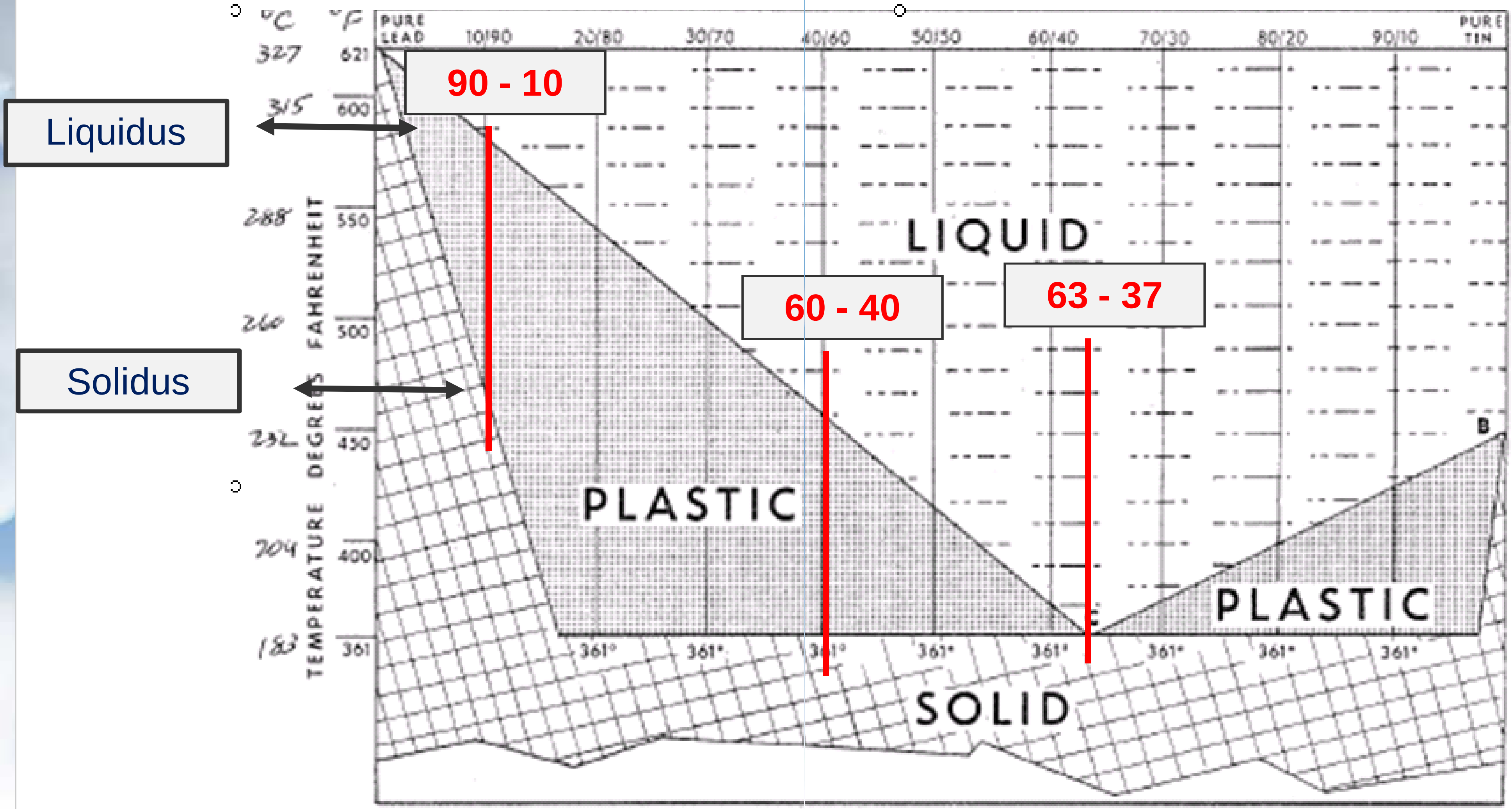
The Profiling Test Vehicle

The Best Test Vehicle is the Actual Product

- Variables
  - Mass (weight of the product)
  - Surface area
  - Thickness
  - The heat capacity
    (the ability of a material to absorb or give up heat)

- TCs should be firmly mounted on critical components
  - High lead solder (90/10)
  - Heat resistance epoxy (Omega Bond 200)
  - Aluminum heat sink tape (Parker Chomerics 405)
  - Kaptan tape

Tin/Lead Solder Phase Diagram



Liquidus

Solidus

90 - 10

60 - 40

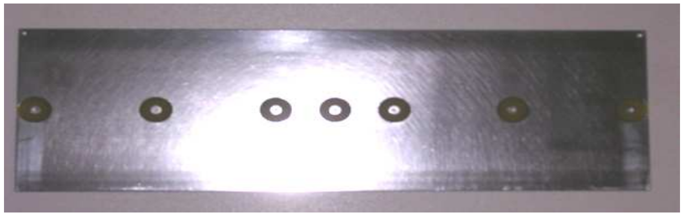
63 - 37

Optional Test Vehicles

- Oven performance can be monitored with other vehicles
  - Consistent - repeatable fixture

•ECD OverRider
  •TCs imbedded in load
  • Includes air TCs

•KIC MVP
  •Simulates your board



•BTU uniformity board
  • Heavy load
  • Mechanical TC attachment
  • Measures temp to w/in 0.5 inches of the rail (±2 ºC)

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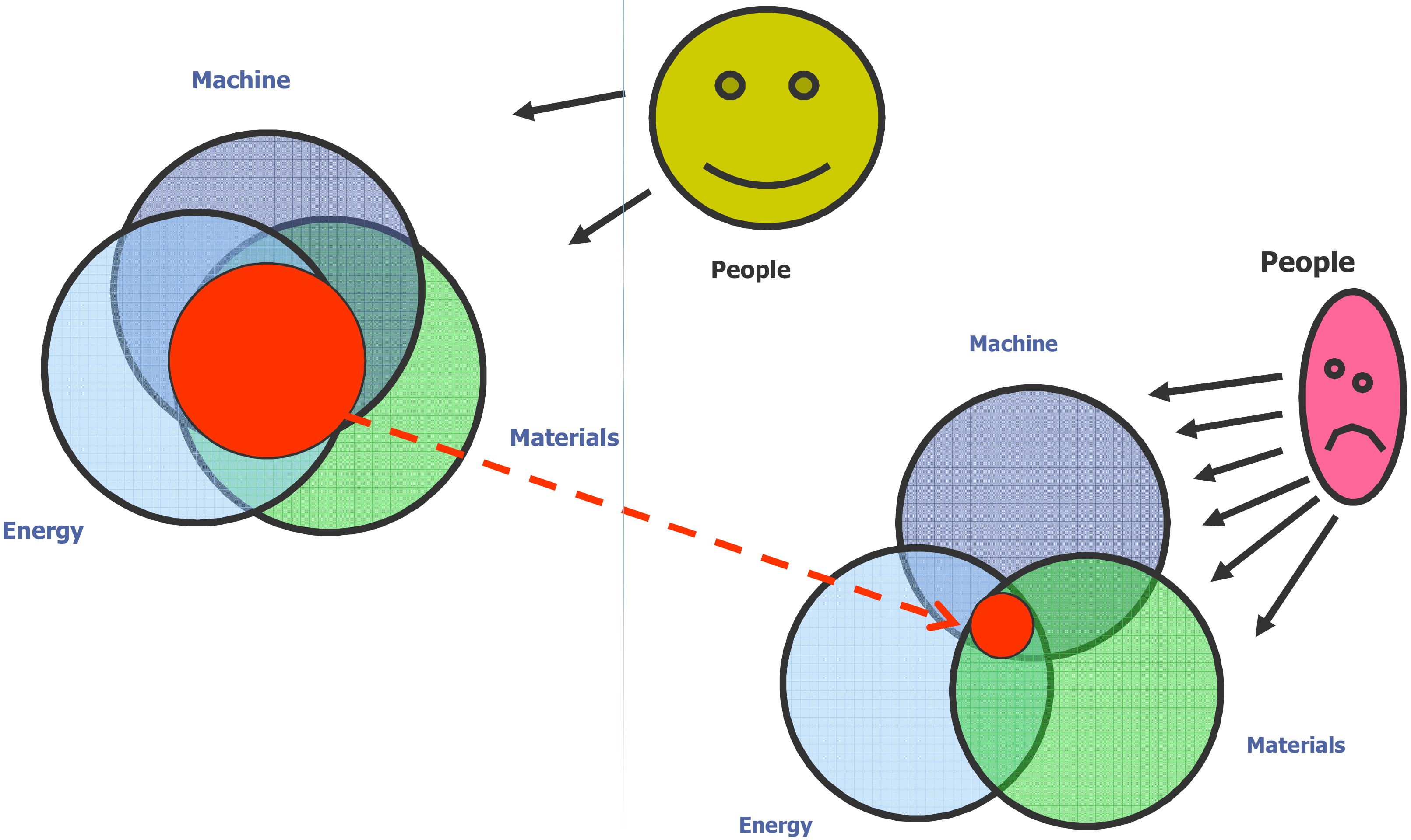
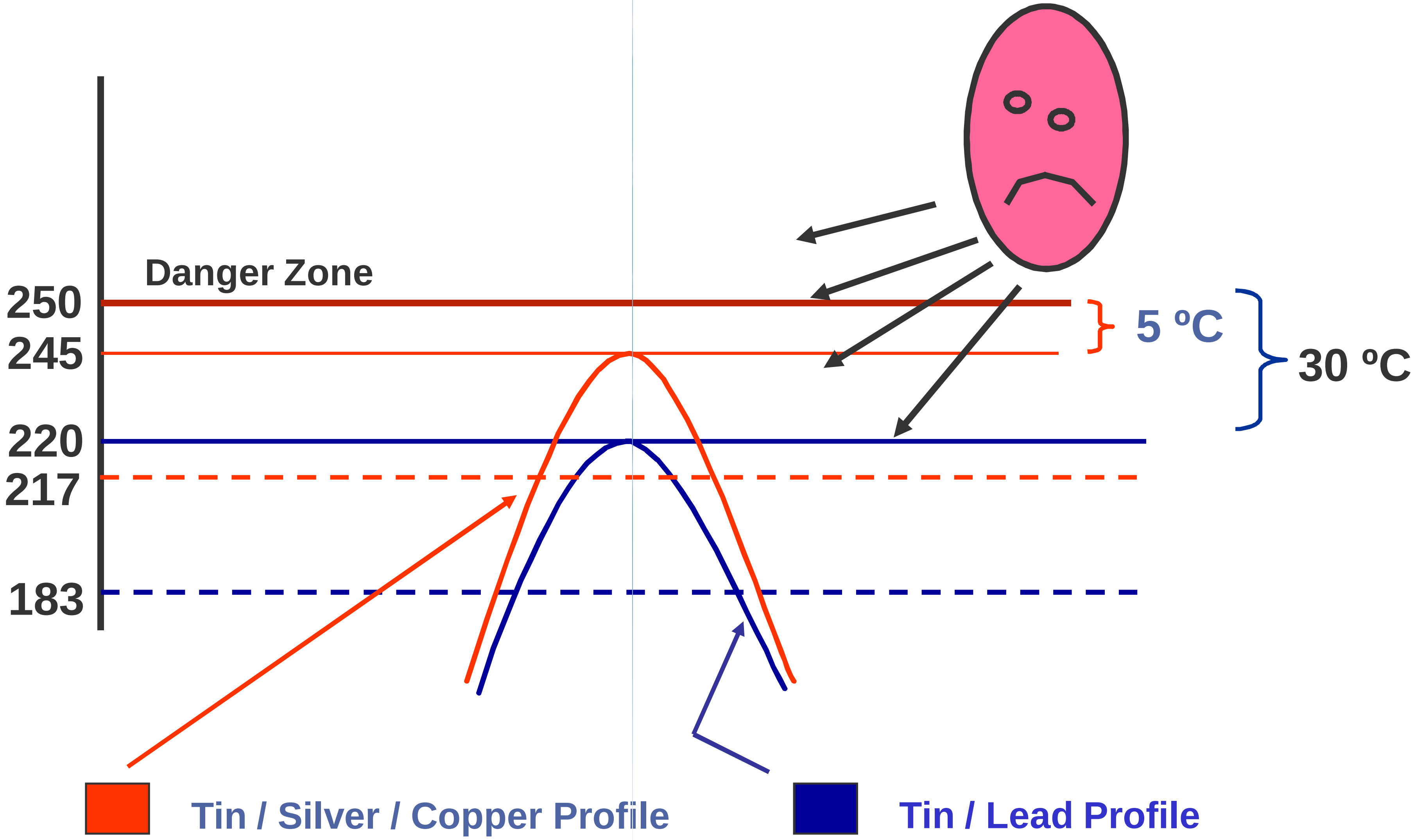
Process Window



Lead-Free Process Window Impact



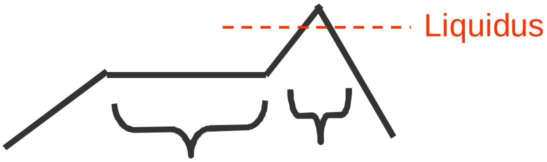
Typical Eutectic vs. SAC Process Windows

	Eutectic	SAC
Heating Ramp	0 – 3 º C/sec	0 – 2.5 ºC/sec
Soak temp	130 -150 ºC	150 – 200 ºC
Soak time	120 – 180 sec	0 – 60 sec
Liquidus	183 ºC	221 ºC
TAL	30 – 90 sec	30 – 60 sec
Peak Temp	210 – 225 ºC	235 – 245 ºC
Cooling ramp	Product dependant	

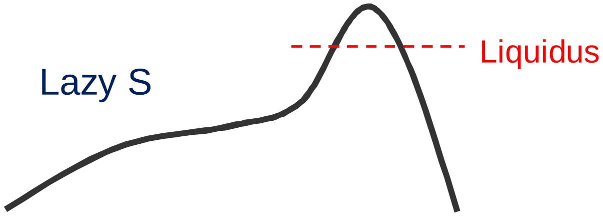
FLUX Activation

Component issues over 250 ºC

Ramp – Soak – Spike



Lazy S

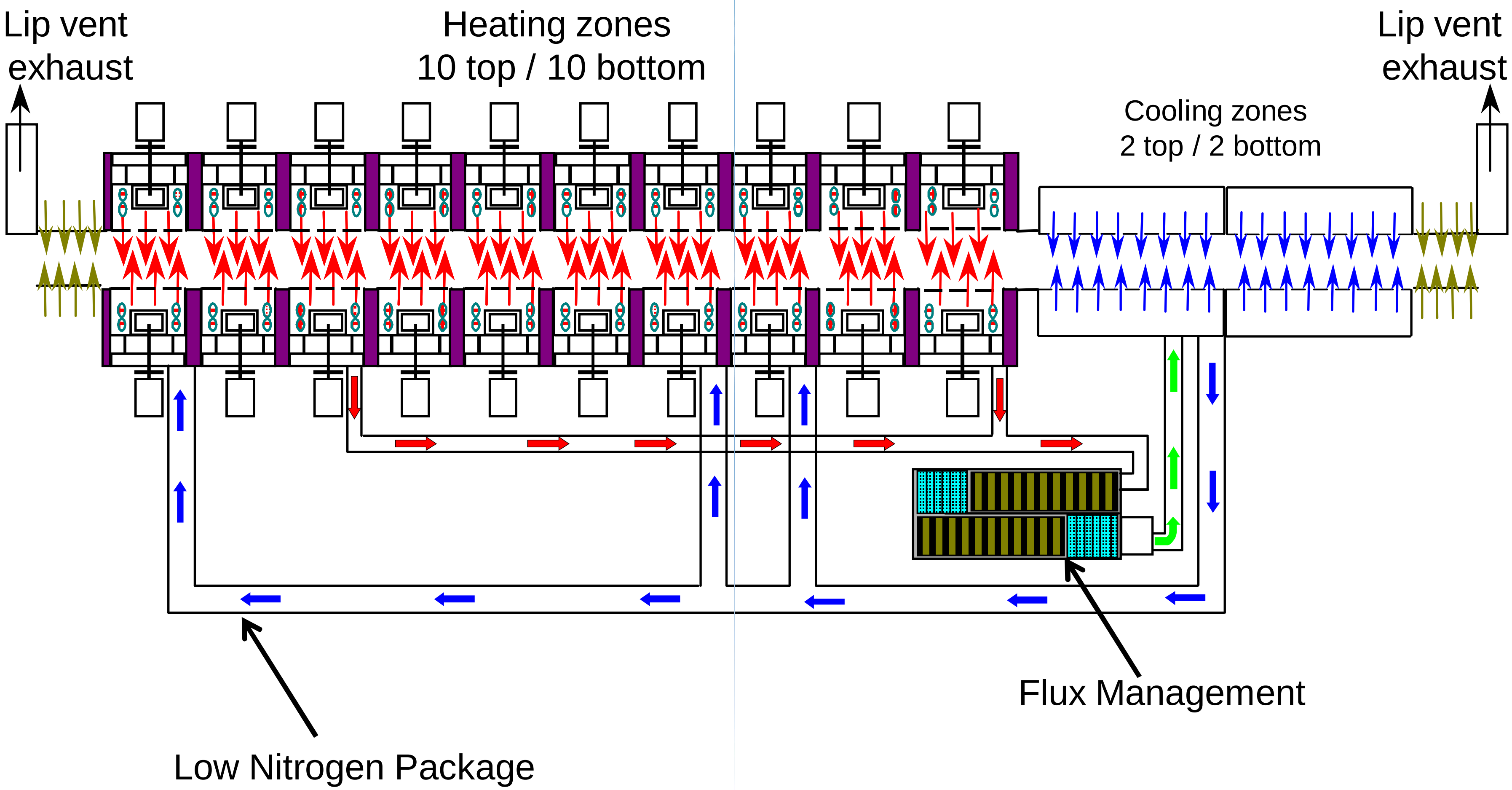


Things that affect the profile

HEAT TRANSFER

- Zone temperatures
- Belt speed
- Gas flows
- Static Pressure
- Product weight

Pyramax 125N



Lip vent exhaust

Heating zones
10 top / 10 bottom

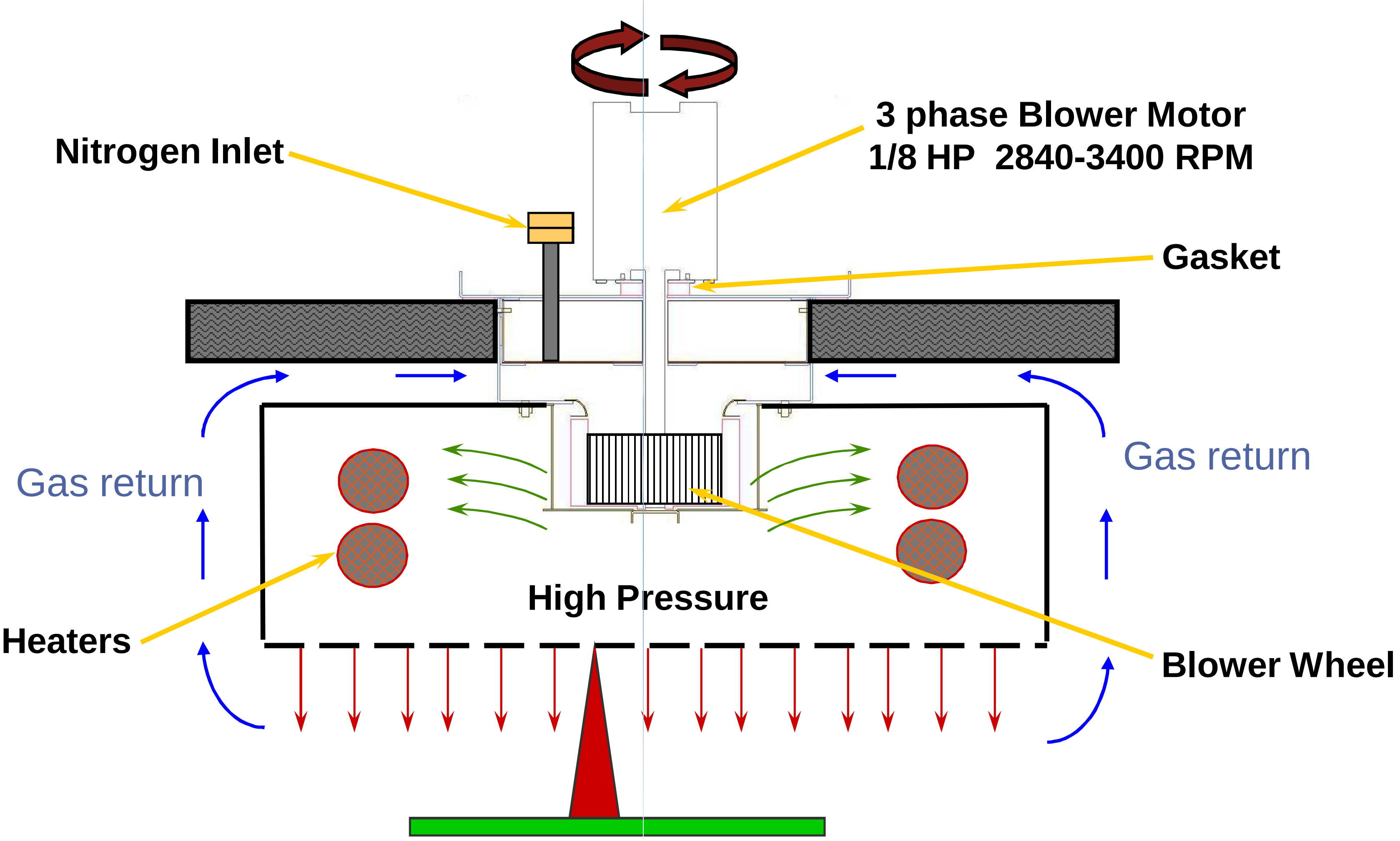
Cooling zones
2 top / 2 bottom

Lip vent exhaust

Flux Management

Low Nitrogen Package

Heated Zone Plenum



Product Coming Towards You!

Energy

Heating (and cooling) is about the transfer of
BTUs / Calories
in a controlled manner.

$$Q = \boxed{h \cdot A} \cdot \boxed{t \cdot \Delta T}.$$

Q = the amount of heat being transferred
(positive/heating or negative/cooling)

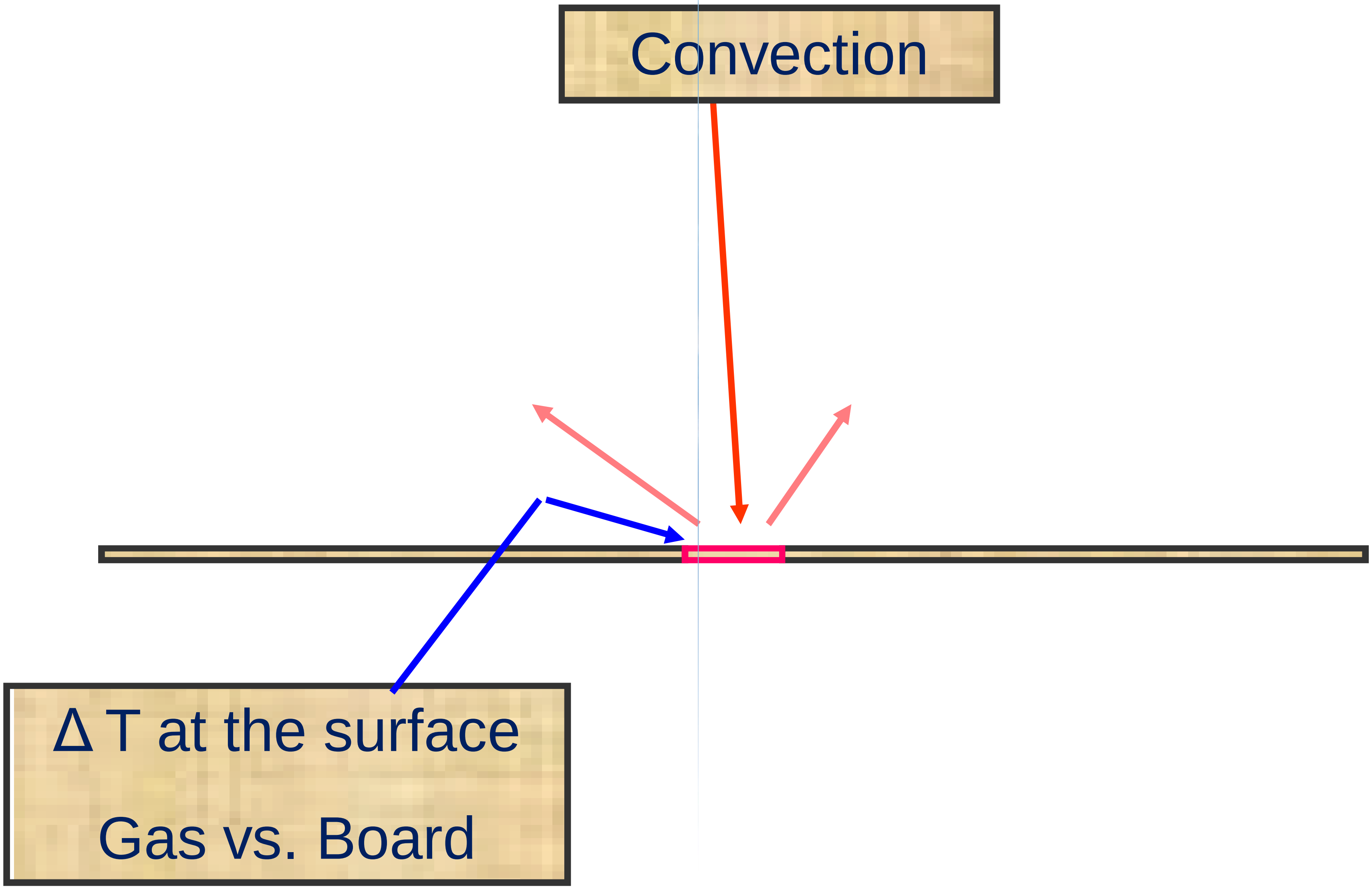
h = the heat capacity of the material
(the ability of a material to absorb or give up heat)

A = the surface area of the product

t = time

ΔT = the temperature differential between the material and the heat source.

Δ T / Temperature



Convection

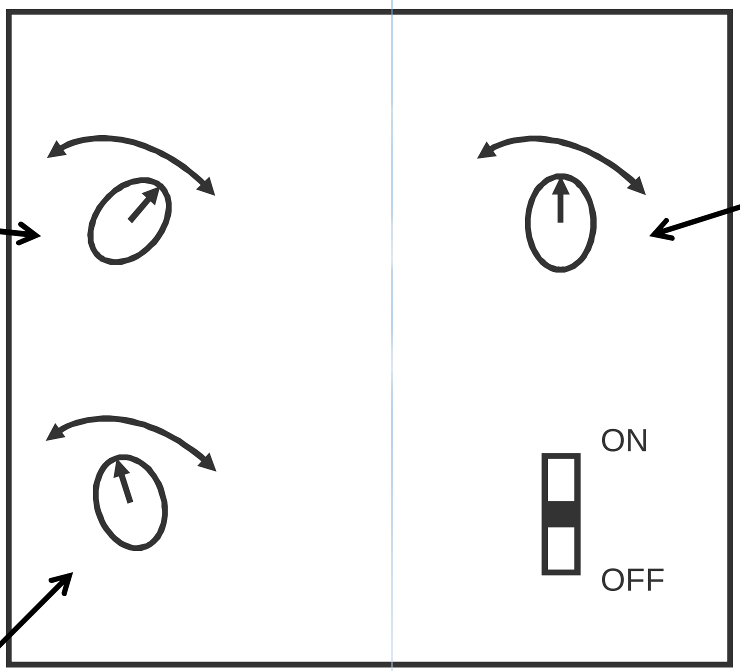
Δ T at the surface

Gas vs. Board

Available Oven Adjustments

t = time

ΔT = the temperature differential



Zone Set Points

ºC

Temperature

Belt Speed

IPM

Time

Static Pressure

IWC or % fan speed

Energy replacement at the board

Equipment Options

- **Heat barriers**
- **Heater power**
- **Cooling Options**

How do the 3 adjustments affect the profile?

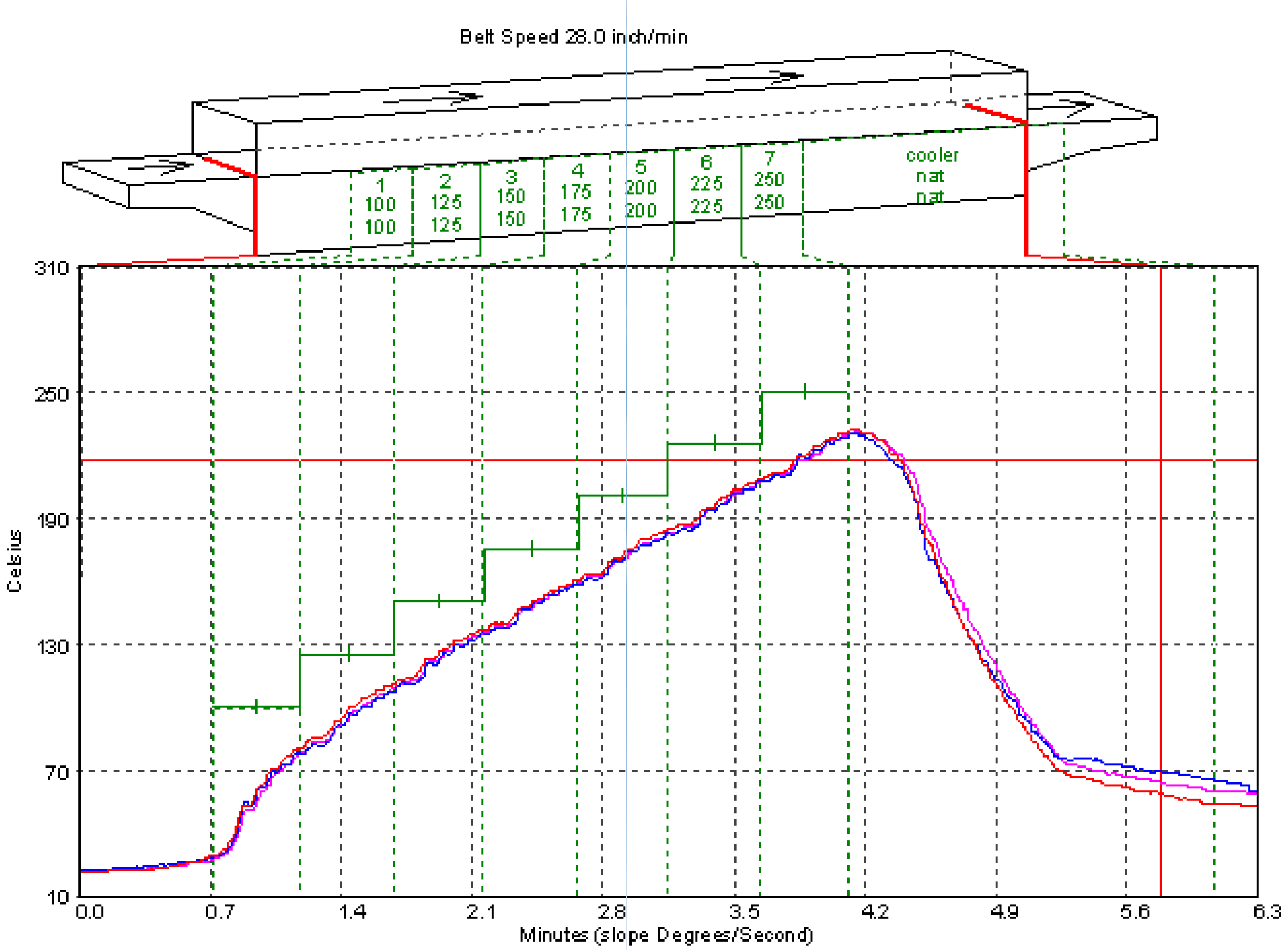
- Temperature 250°C ± 10 °C
- Belt Speed 28 IPM ± 4 IPM
- Static Pressure 1.0 IWC ± 0.3

Peak Temperature

TAL (217)

Delta T @ Peak

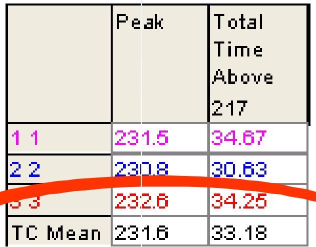
Base Profiles



250°C

1.0 IWC

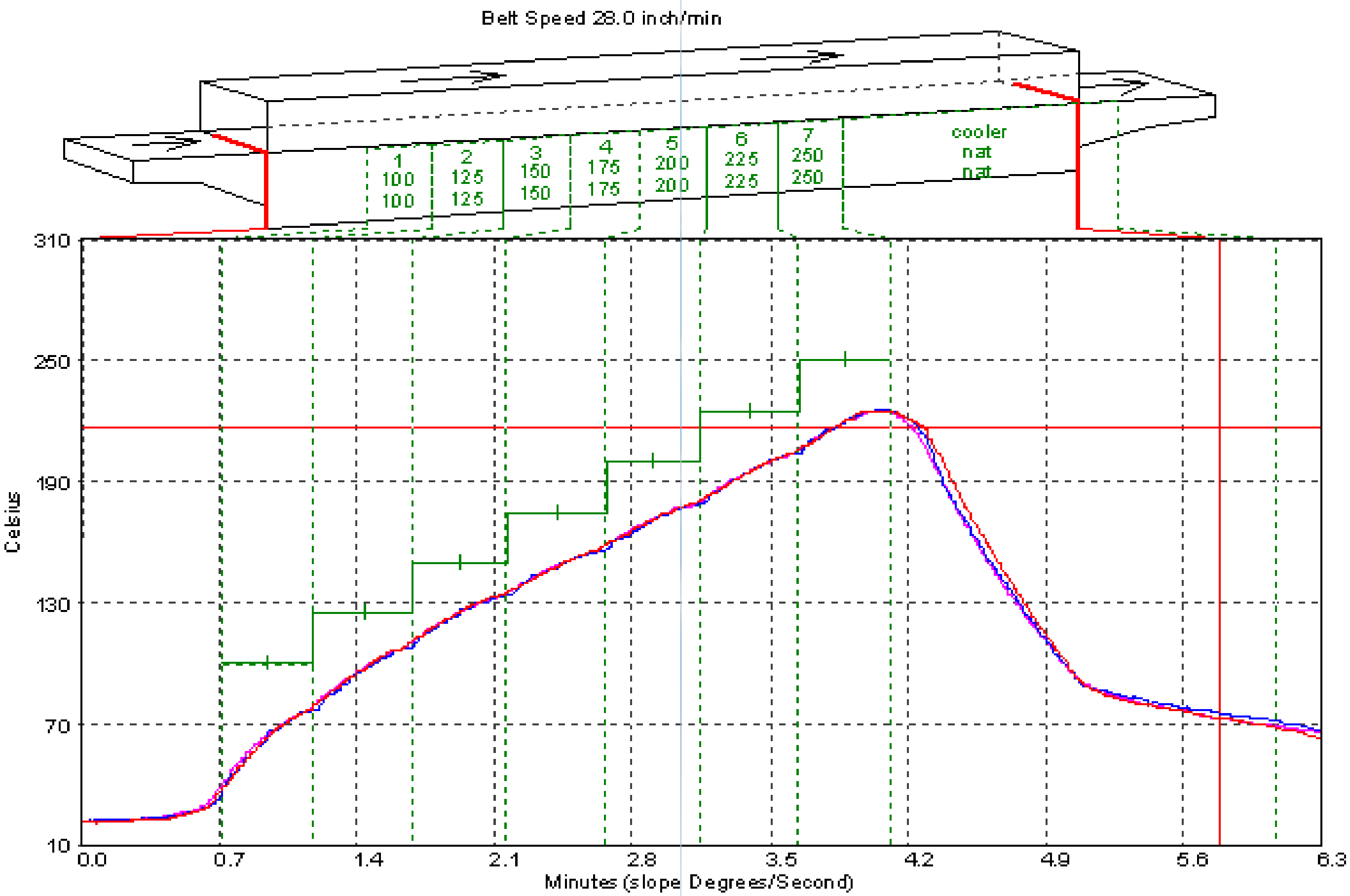
28 IPM

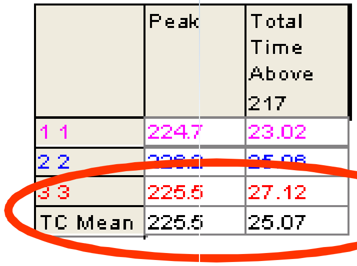


	Peak	Total Time Above 217
1 1	231.5	34.67
2 2	230.8	30.63
3 3	232.6	34.25
TC Mean	231.6	33.18

100 gr Board

Base Profiles



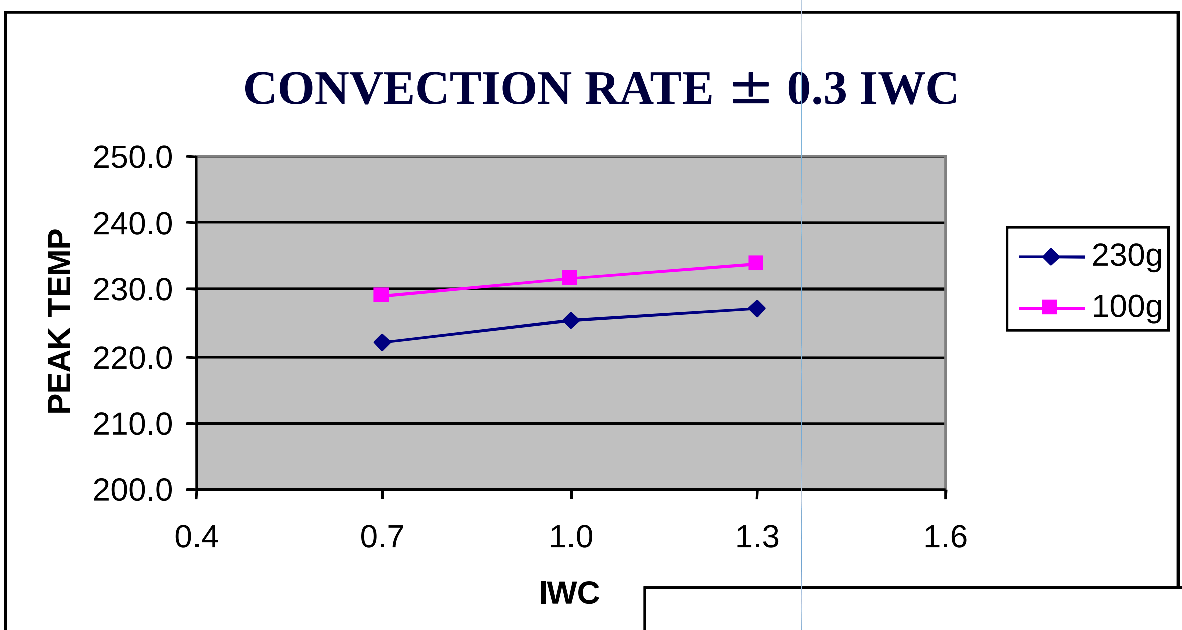


	Peak	Total Time Above 217
1 1	224.7	23.02
2 2	[illegible]	25.08
3 3	225.5	27.12
TC Mean	225.5	25.07

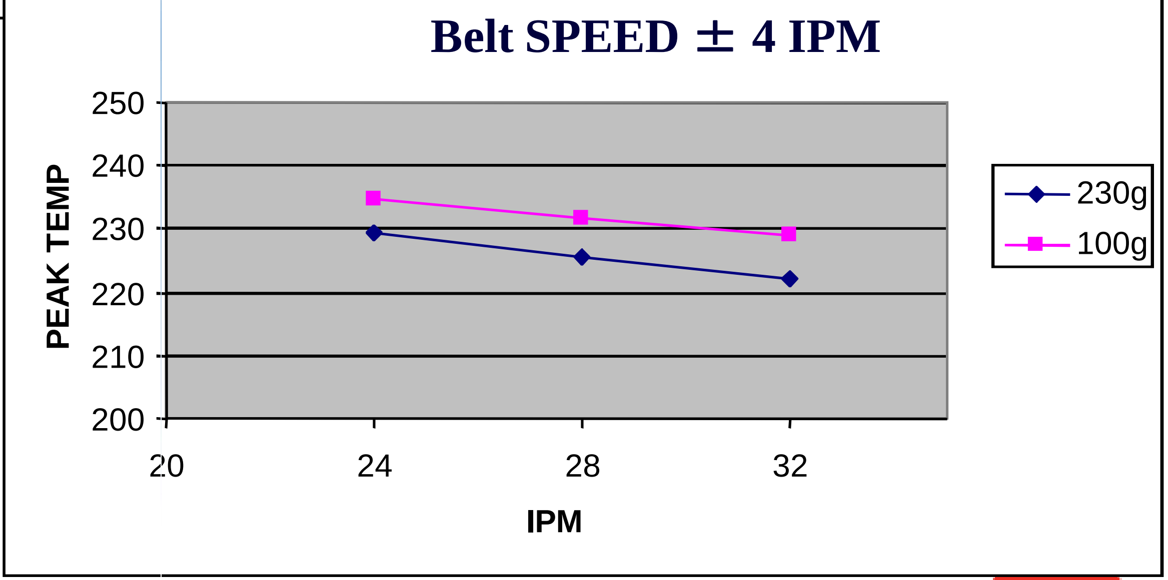
230 gr Board

Peak 231.6 vs. 225.5 ºC
Due to Δ Mass

Peak Temperature

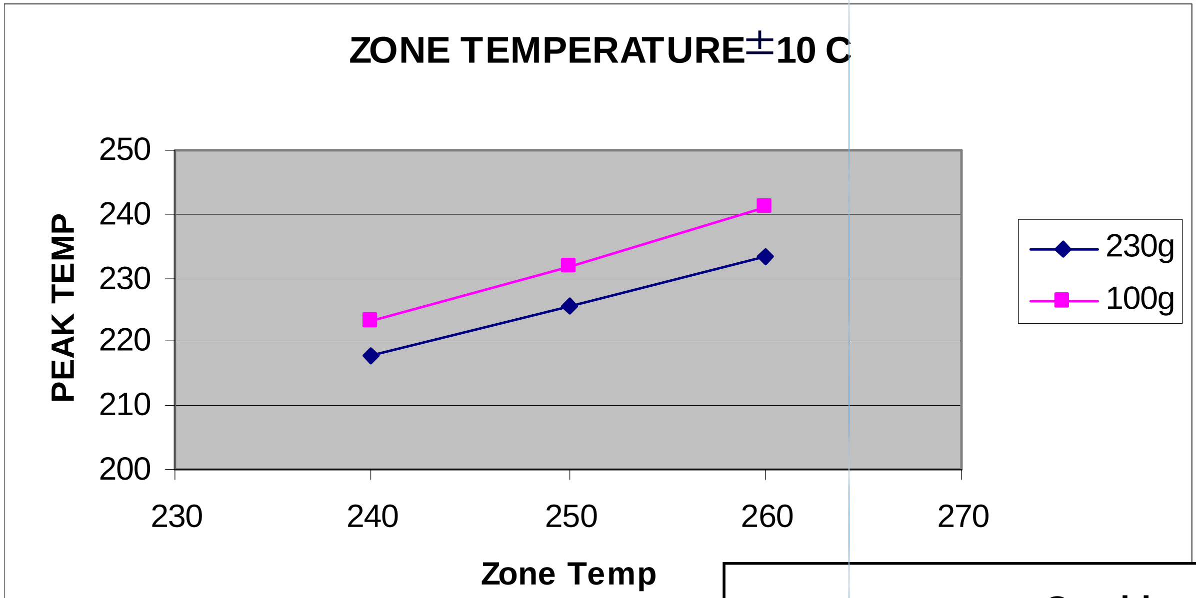


Higher Static Pressure
Raised Peak Temp
by ~5° C



Faster Belt Speed
Lowered Peak Temp
by ~6° C

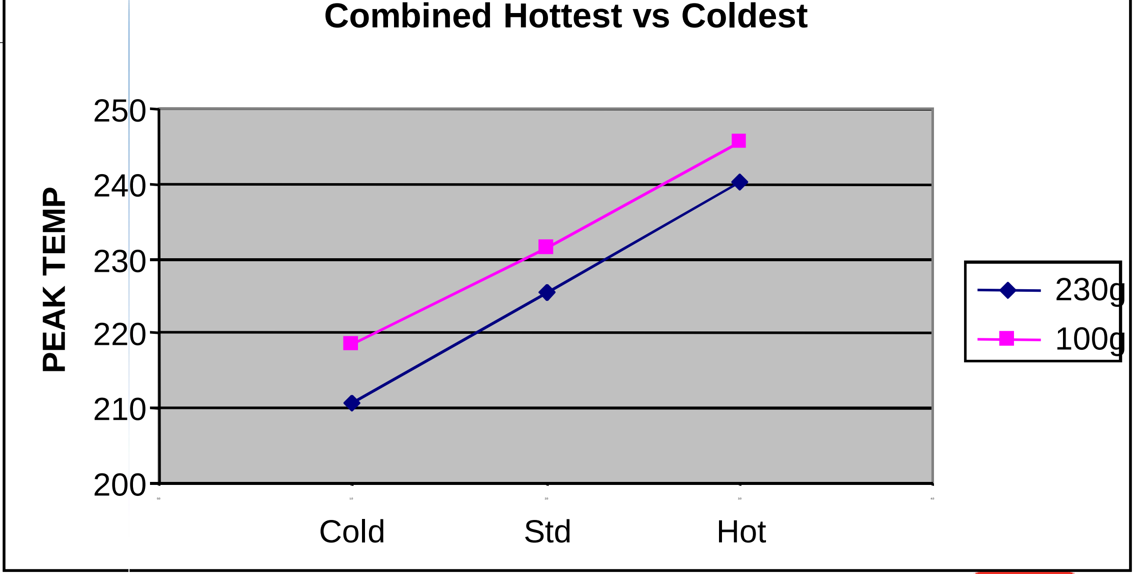
Peak Temperature



ZONE TEMPERATURE±10 C

Higher Zone Temps
Raised Peak Temp
By ~17° C

Everything
By ~28° C



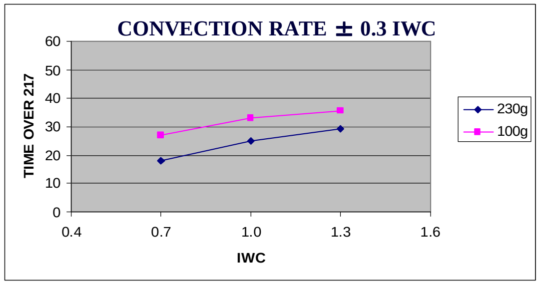
Combined Hottest vs Coldest

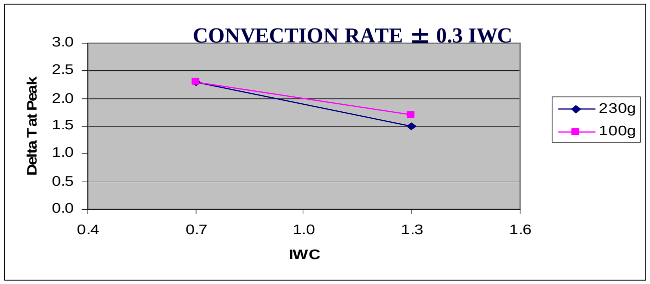
Repeated for TAL & Uniformity

TAL

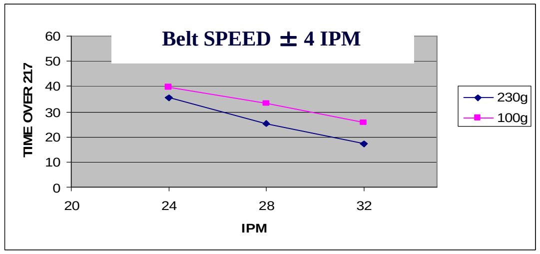
Uniformity

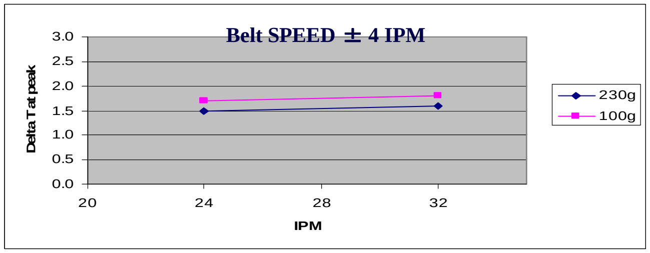
Static Pressure


CONVECTION RATE ± 0.3 IWC

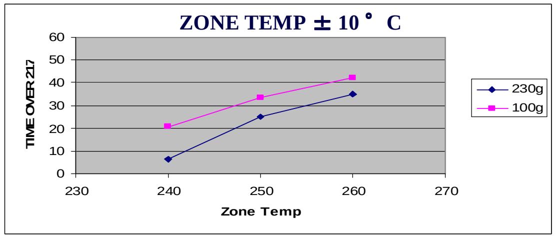

CONVECTION RATE ± 0.3 IWC

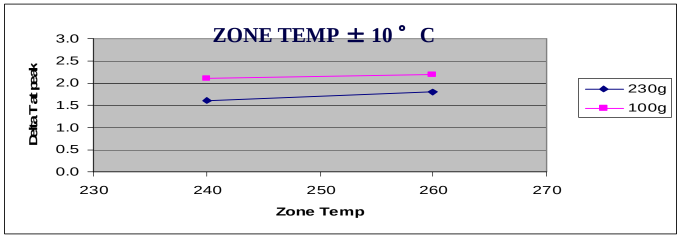
Belt Speed


Belt SPEED ± 4 IPM

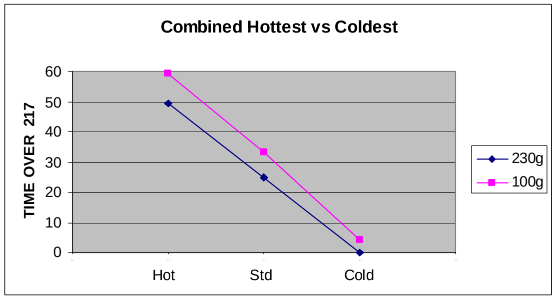

Belt SPEED ± 4 IPM

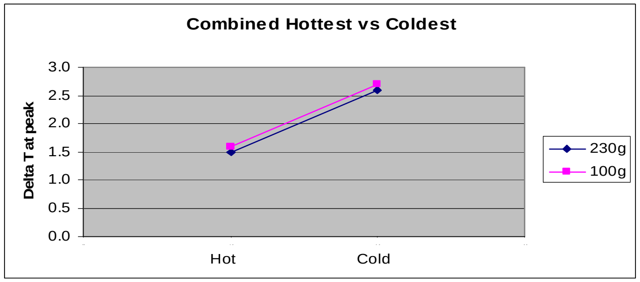
Zone Temperature


ZONE TEMP ± 10 ° C


ZONE TEMP ± 10 ° C

Combined


Combined Hottest vs Coldest


Combined Hottest vs Coldest

Tables (Range)

100 gr Board

	Static Pressure ± 0.3 IWC	Belt Speed ± 4 IPM	Zone Temp ± 10°C	Combined
Peak	4.8°C	5.7°C	17.5°C	27.3°C
TAL	8.9 sec	14.0 sec	21.8 sec	55.2 sec
Δ Temp	0.6°C	0.1 °C	0.1°C	1.1°C

#2

#1

230 gr Board

	Static Pressure ± 0.3 IWC	Belt Speed ± 4 IPM	Zone Temp ± 10°C	Combined
Peak	5.3°C	7.1°C	15.5°C	29.6°C
TAL	14.1 sec	18.5 sec	28.9 sec	49.3 sec
Δ Temp	0.8°C	0.1 °C	0.2°C	1.1°C

Outline

- **Recipe vs. Profile**
- **Material Properties**
- **Why profiles are shaped like they are.**
- **Obtaining profiles**
    - TC Accuracy
    - Profilers
    - The test vehicle
- **Process Window - Eutectic vs. Lead Free**
- **Heat transfer**
- **Oven Control**

References on BTU.COM

http://www.btu.com/support-knowledge-center.htm

"**Oven Adjustment Effects on a Solder Reflow Profile**"
Circuits Assembly – "Getting the Recipe Right"
EM – Asia EPP Germany

Maximizing Process Control with Controlled Convection Rates
Global SMT & Packaging

Oven Selection and Lead-Free Solder Global SMT & Packaging

Effect of High-Temperature Requirements for Lead-Free Solder
Circuits Assembly

Practical Thermal Profile Expectations in a Dual-Lane, Dual-Speed, Reflow Oven Circuits Assembly, EM-Asia

Experiences in Transferring Recipes from an 8-Zone Reflow Oven
Global SMT & Packaging

Improving Reflow w SPC Part I, 2 and 3 Circuits Assembly

Thank You

Questions?