PV Standards and Long Term Thermal Aging (LTTA)

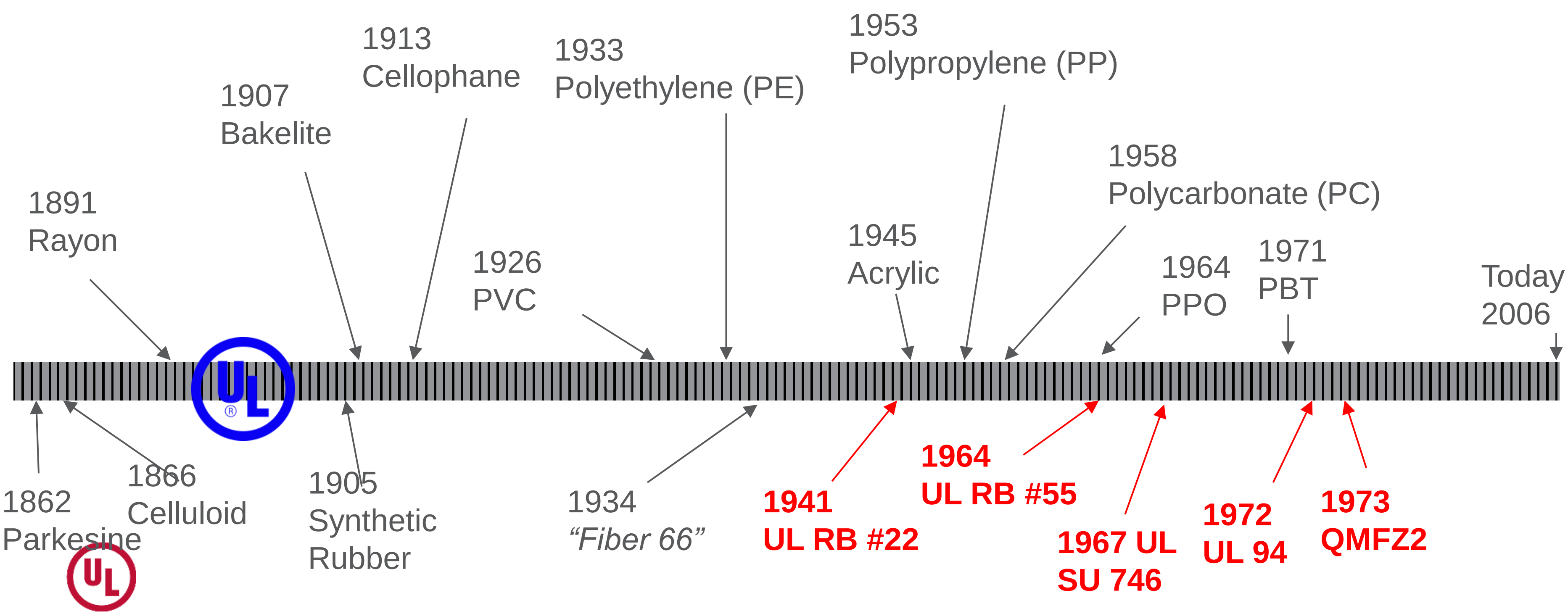
Overview

Agenda

- PV Standards Overview
- Overview of the Relative Thermal Index (RTI)
- The Long Term Thermal Aging (LTTA) Project – Overview
- Developing the Test Program – Selecting Materials
- Developing the Test Program – Selecting Temperatures
- Introduction to Data Analysis

Who we are

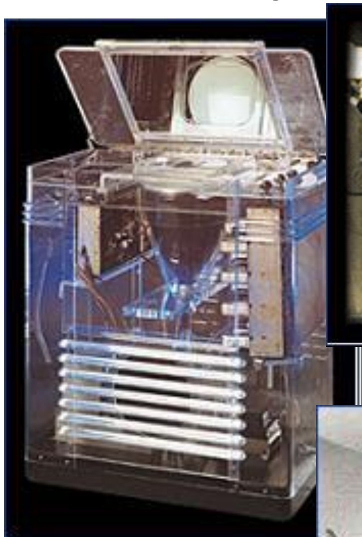
Founded in 1894, UL has earned a reputation as a global leader in product safety and performance standards development, inspecting, testing and certification.

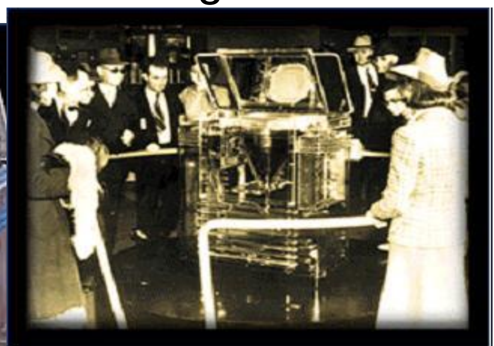


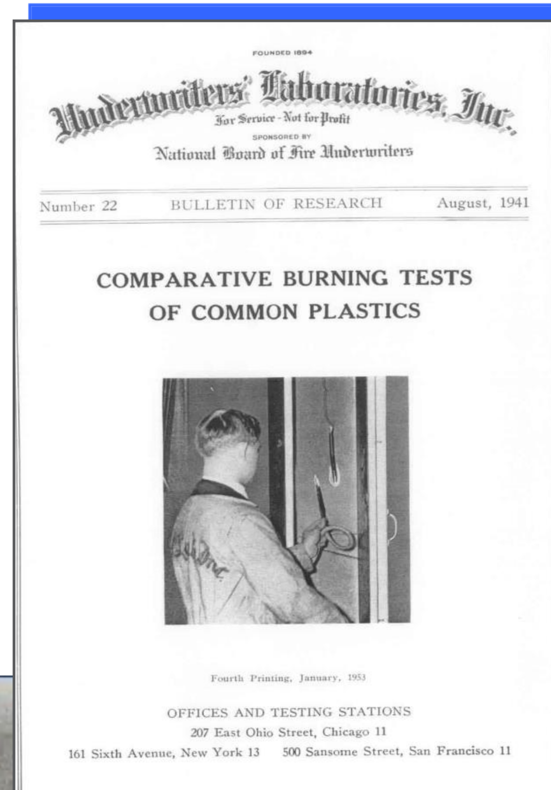
UL's "Path to Plastics"

1938 World's Fair –

- a TV is exhibited for the public with plastics as the major insulating material.







FOUNDED 1894

Underwriters' Laboratories, Inc.

For Service - Not for Profit

SPONSORED BY

National Board of Fire Underwriters

Number 22 BULLETIN OF RESEARCH August, 1941

COMPARATIVE BURNING TESTS OF COMMON PLASTICS

Fourth Printing, January, 1953

OFFICES AND TESTING STATIONS

207 East Ohio Street, Chicago 11

161 Sixth Avenue, New York 13 500 Sansome Street, San Francisco 11

1941: "Comparative burning tests of common plastics"

- UL Research Bulletin #22 by A. J. Perkins (1941)

UL's "Path to Plastics"

1964: "Burning, arcing, ignition, and tracking of plastics used in electrical appliances"

- UL Research Bulletin #55 by L. M. Kline (1964)

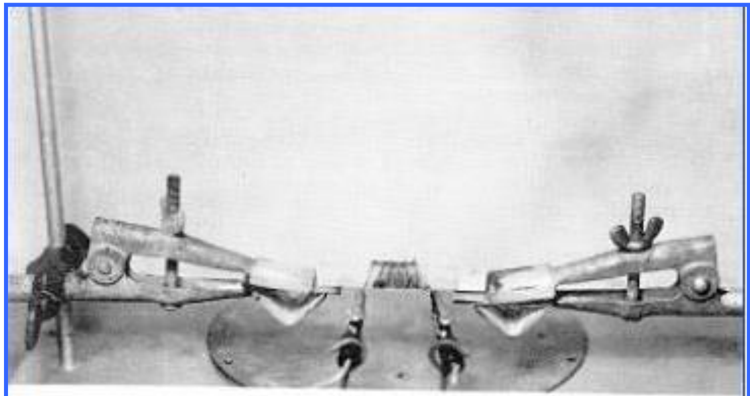


Figure 13. Hot Wire Ignition Test - Sample Before Test.

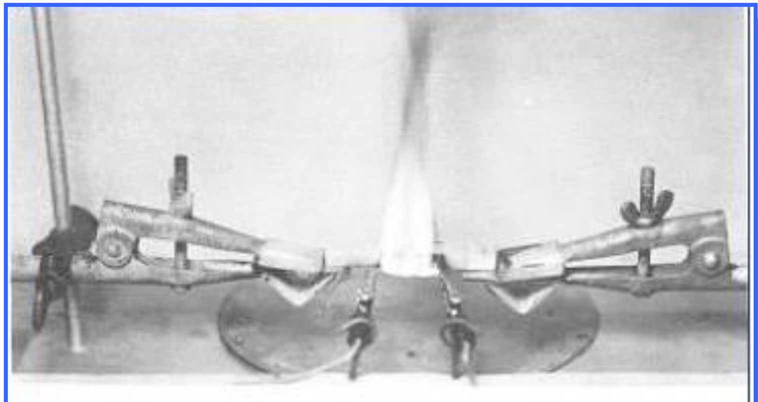


Figure 14. Hot Wire Ignition Test - Sample Under Test.

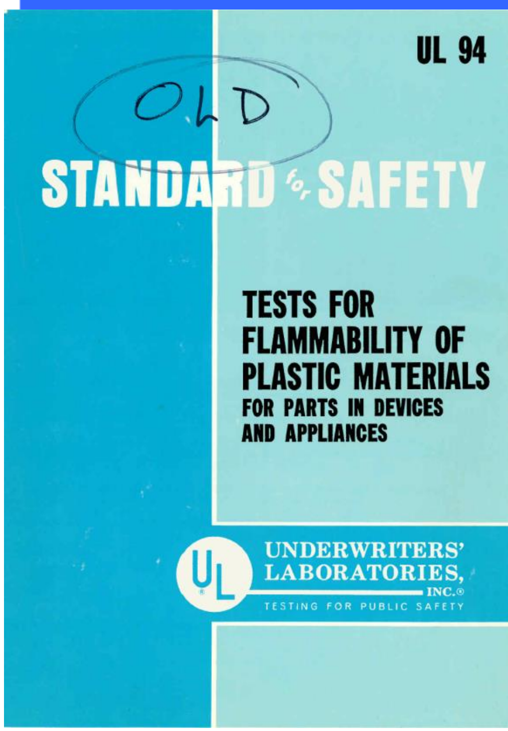
1967: "Guide to Requirements for Polymeric Materials used as Electrical Insulation"

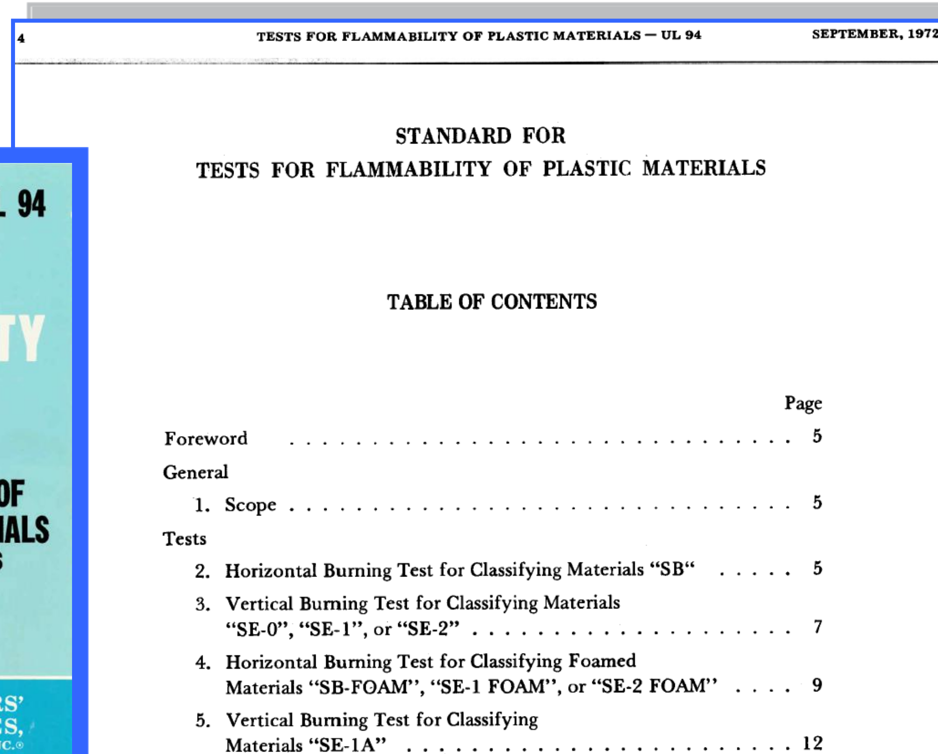
- Subject 746 Bulletin dated March 1, 1967

UL's "Path to Plastics"

UL 94, 1st Edition, September 1972

- Final comments in April 18, 1972 Bulletin





STANDARD FOR
TESTS FOR FLAMMABILITY OF PLASTIC MATERIALS

TABLE OF CONTENTS

Who we are not

- US Government Agency
- Trade Association
- Professional Society
- Publicly Held Company

Overview of the Relative Thermal Index (RTI)

Primary PV Standards

- International
  - IEC 61730
  - IEC 61215 / 61646
- US
  - UL 1703
  - UL 61215/61646
- Electrical Devices – Insulation Coordination
  - IEC 61664
  - UL 840

Polymerics

- Critical properties – Short Term
- Polymers + Heat + Time = ???
  - Long term thermal degradation resulting from cumulative degradation chemistry is most often the critical limiting factor for long term performance capability.
- RTI = Relative Thermal Index *(not ATI)*

Factors Affecting Thermal Performance

- Thermal softening
- Creep
- Performance at temperature
- Thermal Endurance

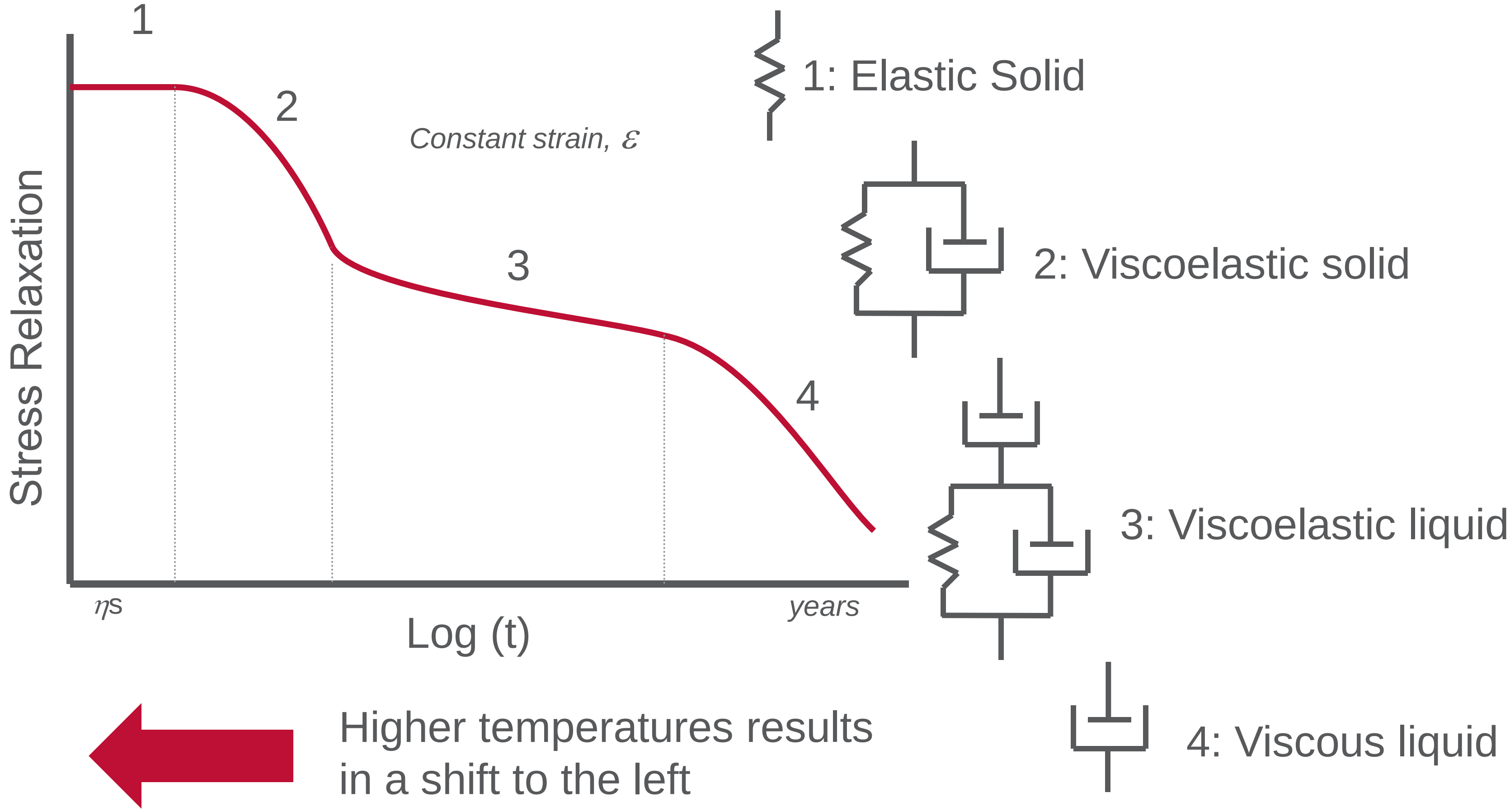
Thermal Softening

- Short-term property
- Thermoplastics Only
- Evaluates how readily a material will distort or deform when exposed to elevated temperatures
  - Heat Deflection
  - Vicat Softening
  - Ball Pressure
  - Mold Stress Relief Distortion

Creep

- Permanent deformation resulting from prolonged application of stress below the elastic limit
- Creep at room temperature is sometimes called cold flow
- Stresses include bending, compressive, or tensile loading; leaf or coil springs; or gravity
- Rigid thermosets do not experience creep (crosslinking restricts chain movement)
- RTI does not address creep

Silly Putty and the Viscoelastic Profile of Plastics



Performance at Temperature

- Indicator of how well a product performs it's function when exposed to elevated temperature

- Long-Term Heat Resistance Test (ASTM D794)
  - Samples heated in oven (gradually increasing temp) until failure
  - Failure = material is no longer acceptable for service
    - Change in appearance, weight, or dimension
    - Change in other property of concern

Thermal Endurance or RTI (746B)

A relative thermal index of a material is an indication of the material's ability to retain a particular property (physical, electrical, etc.) when exposed to elevated temperatures for an extended period of time. It is a measure of the material's thermal endurance. For each material, a number of relative thermal indices can be established, each index related to a specific property and a specific thickness of the material.

Another Way (UL 746B, 6.5)

- Not a “Maximum Operating Temperature” but a maximum temperature below which a material maintains its characteristics over a *reasonable period.*

- Is also referred to as the service temperature of a material

What is Temperature Rating?

The temperature below which a critical property will not be unacceptably compromised through chemical thermal degradation, over the reasonable life of an electrical product

When is RTI required and which RTIs?

Is the material critical for the product’s safety performance?

- *What happens when the material does not exist?*

When is RTI required and which RTIs?

Which are the critical properties of the material in the application?

- Translate end product tests (ex. dielectric withstand, crushing resistance, ball impact) into the basic properties: electrical, strength and impact.

When is RTI required and which RTIs?

Are RTIs equal to, or higher than, the critical hotspot temperatures measured during end-product testing?

What RTI Isn’t

The RTI of a material is not an indication of performance at elevated temperature.

UL iQ – Generic RTI

Component - Plastics **E987654**

ANY PLASTICS CORP.

PLASTIC RD. 1, NORTHBROOK, IL, USA

ABC123 +

Polyamide 66 (PA66), furnished as pellets

Color	Min Thk (mm)	Flame Class	HWI	HAI	RTI Elec	RTI Imp	RTI Str
ALL	1.5	V-2	3	0	65	65	65
	3.0	V-0	1	0	65	65	65
	6.0	V-0, 5VA	0	0	65	65	65

Comparative Tracking Index (CTI): **0**

High-Voltage Arc Tracking Rate (HVTR): **1**

Dielectric Strength (kV/mm): **30**

Dimensional Stability (%): **-**

High Volt, Low Current Arc Resis (D495): **4**

Volume Resistivity (10^x ohm-cm) : **12**

+ - Material designations may be followed by suffix numbers and/or letter(s) denoting color.

UL94 small-scale test data does not pertain to building materials, furnishings and related contents. UL94 small-scale test data is intended solely for determining the flammability of plastic materials used in the components and parts of end-product devices and appliances, where the acceptability of the combination is determined by Underwriters Laboratories Inc.

Report Date: 0000-00-00

Last Revised: 2008-08-01

Underwriters Laboratories Inc®

UL iQ – Long Term Aging RTI

Component - Plastics

E987654

ANY PLASTICS CORP.

PLASTIC RD. 1, NORTHBROOK, IL, USA

ABC123 +

Polyamide 66 (PA66), furnished as pellets

Color	Min Thk (mm)	Flame Class	HWI	HAI	RTI Elec	RTI Imp	RTI Str
ALL	1.5	V-2	3	0	140	110	120
	3.0	V-0	1	0	140	120	130
	6.0	V-0, 5VA	0	0	140	120	130

Comparative Tracking Index (CTI): 0

High-Voltage Arc Tracking Rate (HVTR): 1

Dielectric Strength (kV/mm): 30

Dimensional Stability (%): -

High Volt, Low Current Arc Resis (D495): 4

Volume Resistivity (10^x ohm-cm) : 12

+ - Material designations may be followed by suffix numbers and/or letter(s) denoting color.

UL94 small-scale test data does not pertain to building materials, furnishings and related contents. UL94 small-scale test data is intended solely for determining the flammability of plastic materials used in the components and parts of end-product devices and appliances, where the acceptability of the combination is determined by Underwriters Laboratories Inc.

Report Date: 0000-00-00
Last Revised: 2008-08-01

Underwriters Laboratories Inc®

Degradation Mechanisms

- Oxidation
  - Chemical
  - Thermal
- Hydrolytic depolymerization
- Crosslinking
- Crazing

Oxidation

- Recombination of elements in polymer with environmental oxygen
- Increase in temperature increases oxidation rate
- *Aging process utilizes thermal-chemical oxidation*

Aging Theory

IEEE

- *1:* **Recommended Practice - General Principles for Temperature Limits in the Rating of Electrical Equipment and for the Evaluation of Electrical Insulation**
- *98:* **Standard for the Preparation of Test Procedures for the Thermal Evaluation of Solid Electrical Insulating Materials**
- *101:* **Guide for the Statistical Analysis of Thermal Life Test Data**

A comparison of the thermal-aging characteristics of one material of proven field service at a particular temperature level with the thermal-aging characteristics of another material with no field service history provides a means for estimating the relative thermal index level at which the second material might also provide acceptable field service.

Arrhenius, the Equation

$$k = Ae^{-\frac{E}{RT}}$$

$$\log_e K = \log_e A - \frac{E}{RT}$$

$$\log_e K = -\left(\frac{E}{R}\right) * \left(\frac{1}{T}\right) + \log_e A$$

$$\mathbf{Y = M * X + B}$$

k = Specific Reaction Rate

A = Constant

E = Reaction Activation Energy

R = Ideal Gas Constant

T = Absolute Temperature

This reduces to linear plot between:

- 1/T (reciprocal temperature) and
- ln k (natural log of specific reaction rate)

Slide 28

UL 746B vs IEC 60216

- TI: IEC 60216-3 method does not incorporate control concept
  - Correlation time is set at 20,000 hours
- RTE: IEC 60216-5 (Fixed Temperature method)
- IEC 60216-6 (Fixed Time method)

Long Term Thermal Aging (LTTA)–
Overview

Material Properties

What is appropriate for this material type?

- Impact Property
  - Tensile
  - Izod or Charpy
  - Other
- Strength Property
  - Tensile
  - Flexural
  - Other
- Electrical Property
  - Dielectric
  - Other

Primary Properties

- Expected to reach end-of-life for each of the test temperatures
  - When there is no information on degradation of individual properties, assume all are primary
  - If specific properties are known to degrade more rapidly, assign them as primary and evaluate others as secondary
- Monitored throughout the program

Secondary Property

Property which is not expected to reach end point before the primary properties

- ❑ Flammability
  - Vertically rated materials only
- ❑ Electrical (sometimes)
- ❑ Strength (rarely)
- ❑ Impact (never)

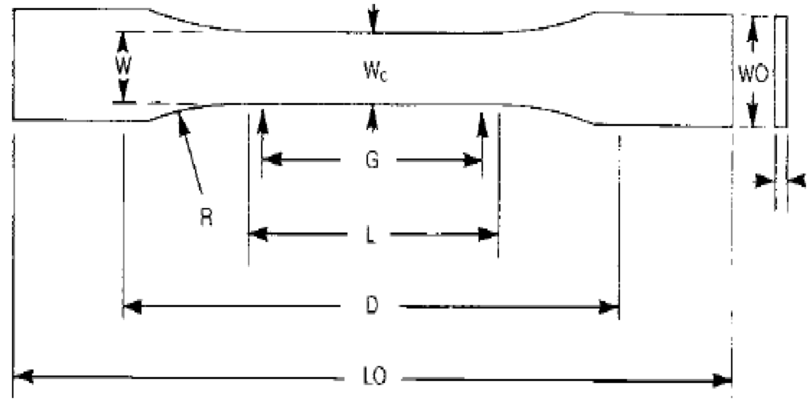
Samples (ASTM)

ASTM

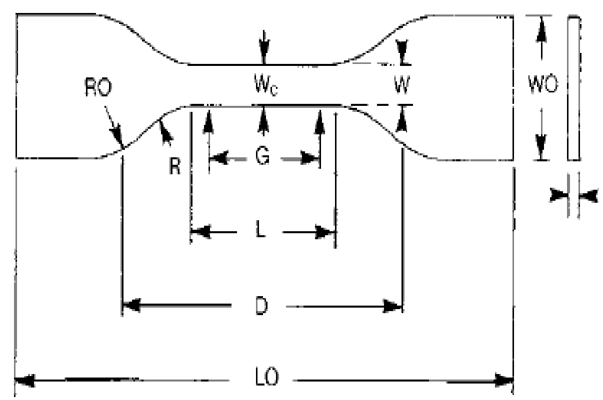
- Type I for most applications
- Type IV for elastomeric materials

Machined Samples

- Same direction
- Inspect radius
  - Break in Clamp



TYPES I, II, III & V



TYPE IV

Samples (ISO)

ISO 3167

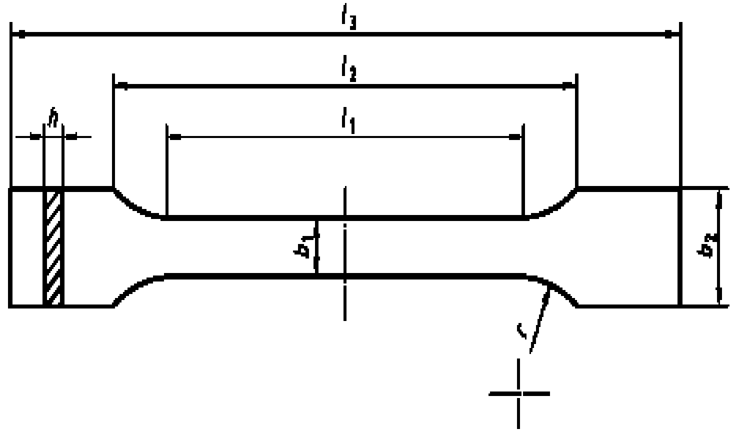
- Multi-purpose Test Specimen

Molded: Type 1A

Machined: Type 1B

Different dimensions for machined samples!!

- Higher radius
- Shorter middle region



	Specimen type	A	B
l_3	Overall length[a]	$\geqslant$ 150 Recommended value[b] 170	$\geqslant$ 150
l_1	Length of narrow parallel-sided portion	80 ± 2	$60{,}0 \pm 0{,}5$
r	Radius	20 to 25 Recommended value[b] 24 ± 1	$\geqslant$ 60[c] Recommended value[b] $60{,}0 \pm 0{,}5$
l_2	Distance between broad parallel-sided portions[d]	104 to 113	106 to 120 Recommended range[b] 106 to 110
b_2	Width at ends	$20{,}0 \pm 0{,}2$	
b_1	Width of narrow portion	$10 \pm 0{,}2$	
h	Thickness	$4{,}0 \pm 0{,}2$	


UL
Underwriters Laboratories Inc.
Melville Division
1285 Walt Whitman Road
Melville, NY 11747-3081 USA
www.ul.com
tel: 1 631 271 6200
fax: 1 631 271 6259

Impact Strength

Tensile Impact

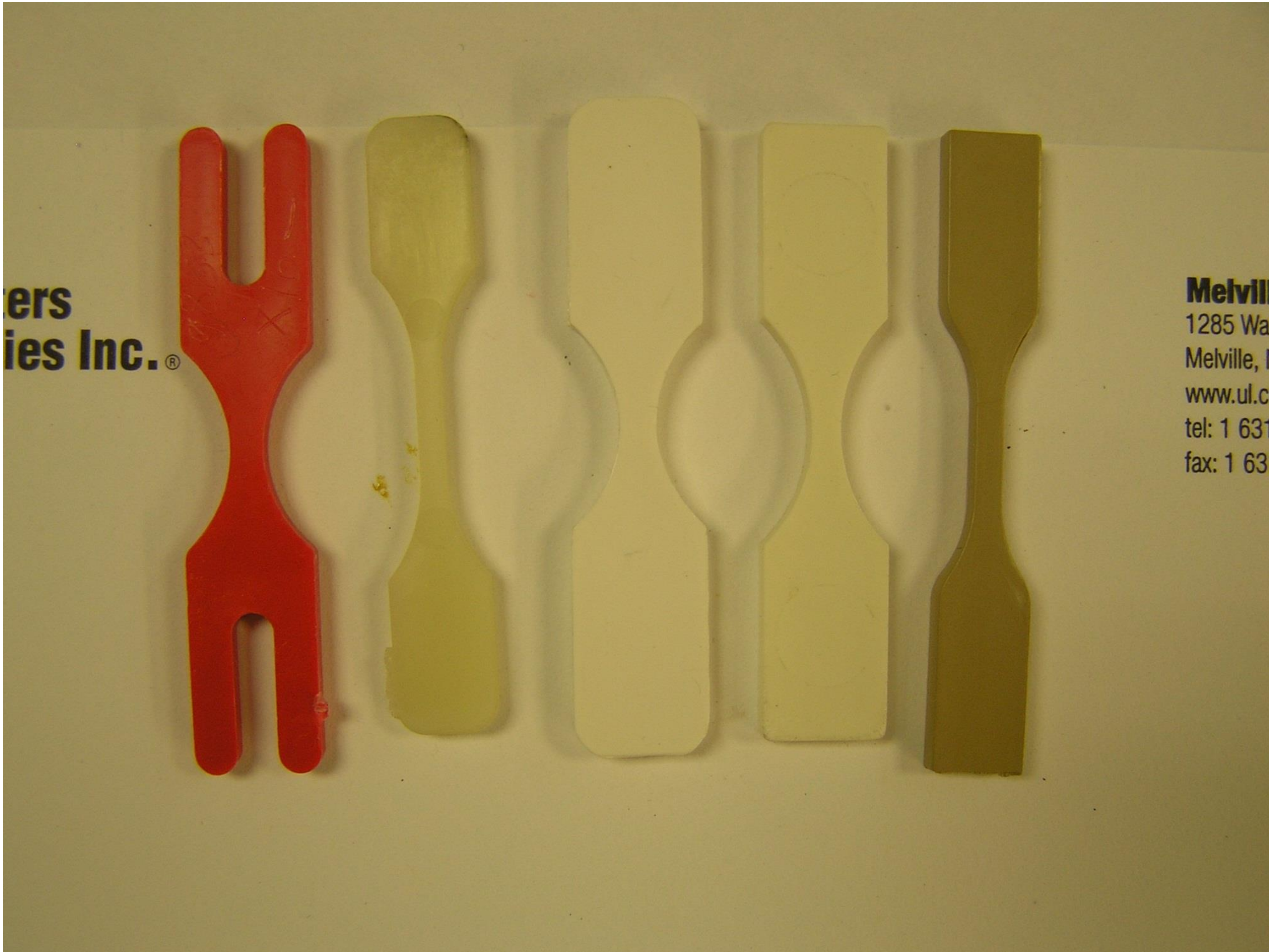
- ASTM D1822 and ISO 8256
  - Not equivalent *(Note: ASTM TI preferred)*

Izod Impact

- ASTM D256 and ISO 180
  - Not equivalent
  - ISO = Notch A and edgewise only

Charpy Impact

- ASTM D6110 and ISO 179
  - Not equivalent *(Note: ISO CI preferred)*


ters
ies Inc.®
Melvill
1285 Walt
Melville, N
www.ul.co
tel: 1 631
fax: 1 631

Charpy Impact

Similar to Izod, except

- Sample orientation (horizontal)
- No clamping pressure

Edgewise samples preferred

Dielectric Strength

ASTM D149 and IEC 60243

- Similar but not exactly equivalent
  - Different electrode preferences
- All insulators exhibited some type of leakage
  - This results in localized heating which facilitates greater voltages until breakdown occurs

LTTA tests on just the minimum thickness

- Even if Recognized at just 3.0 mm, test DS at 0.75 mm

Per UL 746A

- Rate of rise = 500 V/s
- Test in air; for LTTA, we prefer oil (industry norm)

Specimen Thickness

- Electrical
  - Minimum thickness desired
- Impact
  - Testing at 3 or 4 mm nominal thickness represents thinner, if thinner thickness evaluated for non-impact property (see Offset Principle)
- Strength
  - 3 mm plus minimum thickness desired

Specimen Quantity - General

- Assumes end-of-life reached within number of aging cycles indicated in the delayed-set schedules
- Applies to Proposed and Control Materials
- Assumes all properties are primary

Specimen Quantity – Rigid Non-polypropylene

Strength and Impact

- 3 mm thickness: 290 specimens
- Reduced thicknesses: 120 specimens each

Dielectric

- 0.8 mm thickness: 230 specimens

Flame (Candidate only)

- Minimum thickness: 140 specimens

Selecting Materials

Why Do I Need a Control?

- Use of control is used to normalize lab variations
  - Variations in oven temperatures or other lab elements happen to both control and candidate
- Allows for establishing an *R*TI, since the temperature is *relative* to another material

General (UL 746B)

- Established RTI and good field service at it's rating
- Preferable to have same generic type as candidate, tested in same thickness, and have RTI close to expected RTI of candidate
- Tested in same ovens as candidate unless performance ranges are significantly different or contamination problems occur

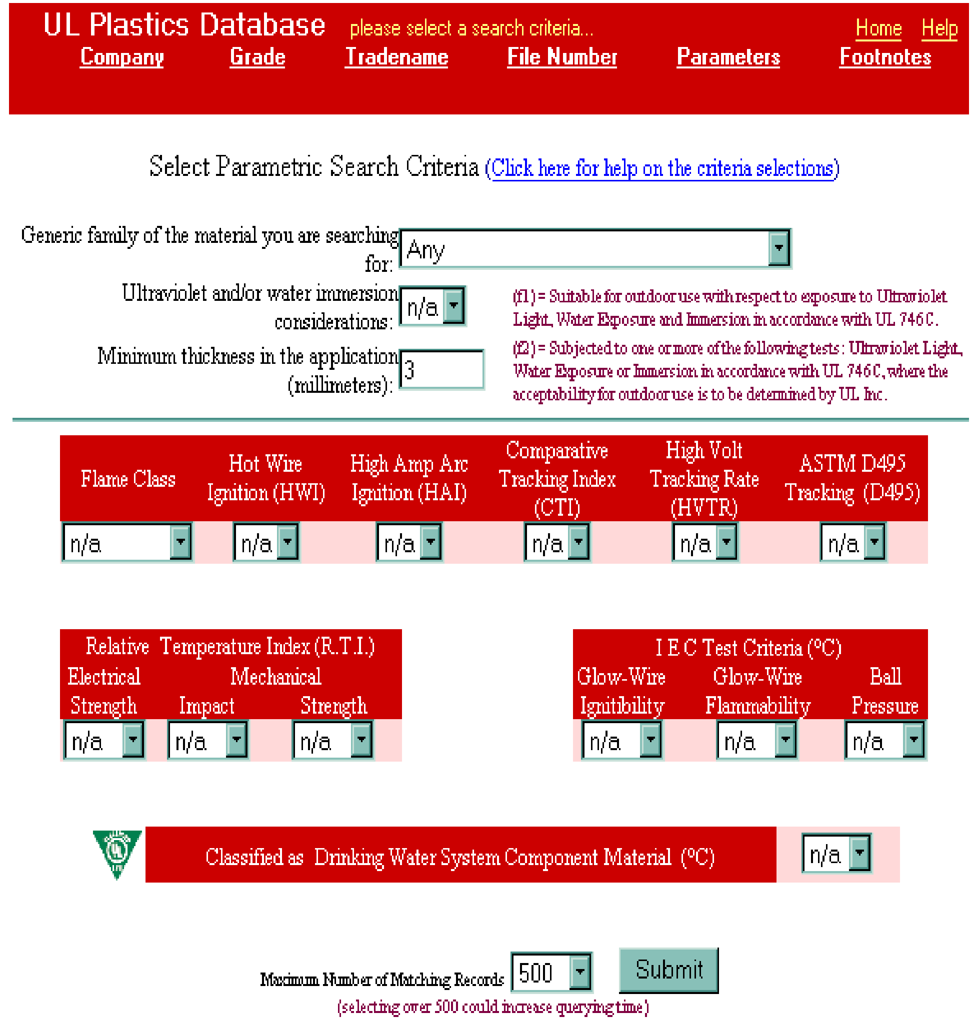
Selection of Controls

Goal = Similar degradation mechanisms

- "… with a record of good field service at its rated temperature."

Use Parameter Search

- Same mfr?
- Same generic base resin?
- ±10 C°?
- Descriptive similarities?

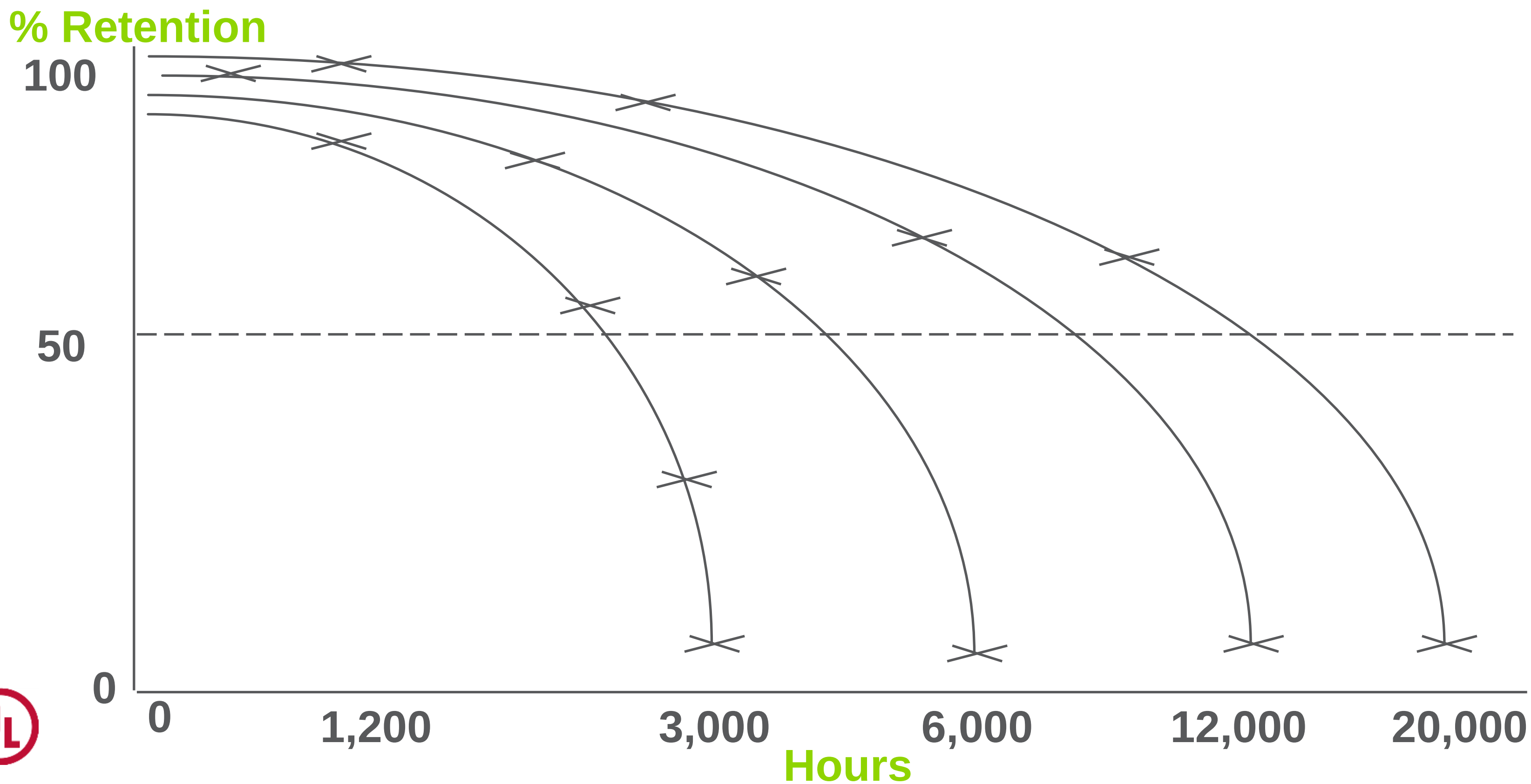


Module 5: Introduction to Data Analysis

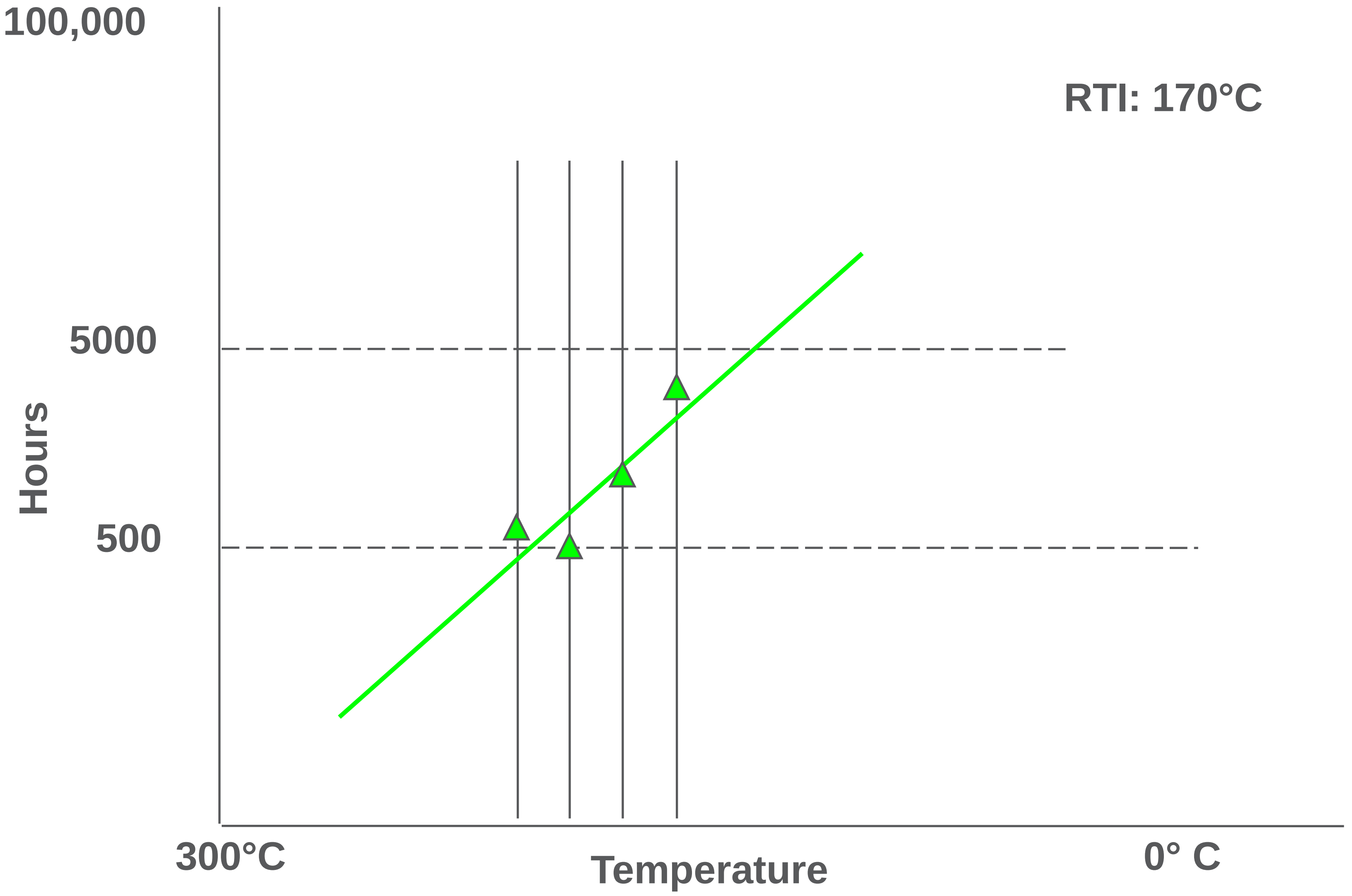
F50 Curve Fit

Why 50%

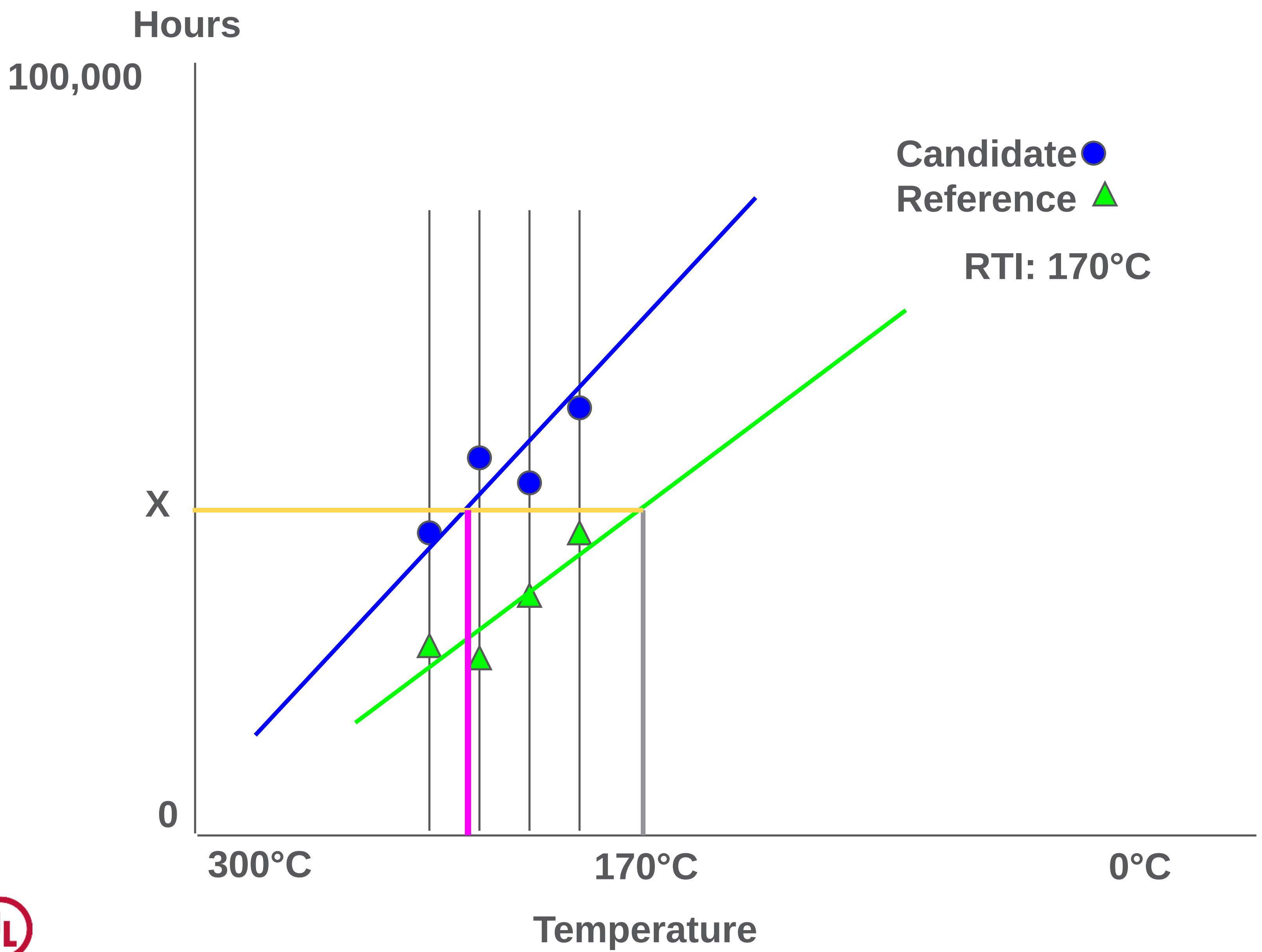
- Arbitrary point of measurement
- Assumption: 2x Safety Factor built in



Reference Material Aging



Calculation of Candidate RTI



UL 746B vs IEC 60216

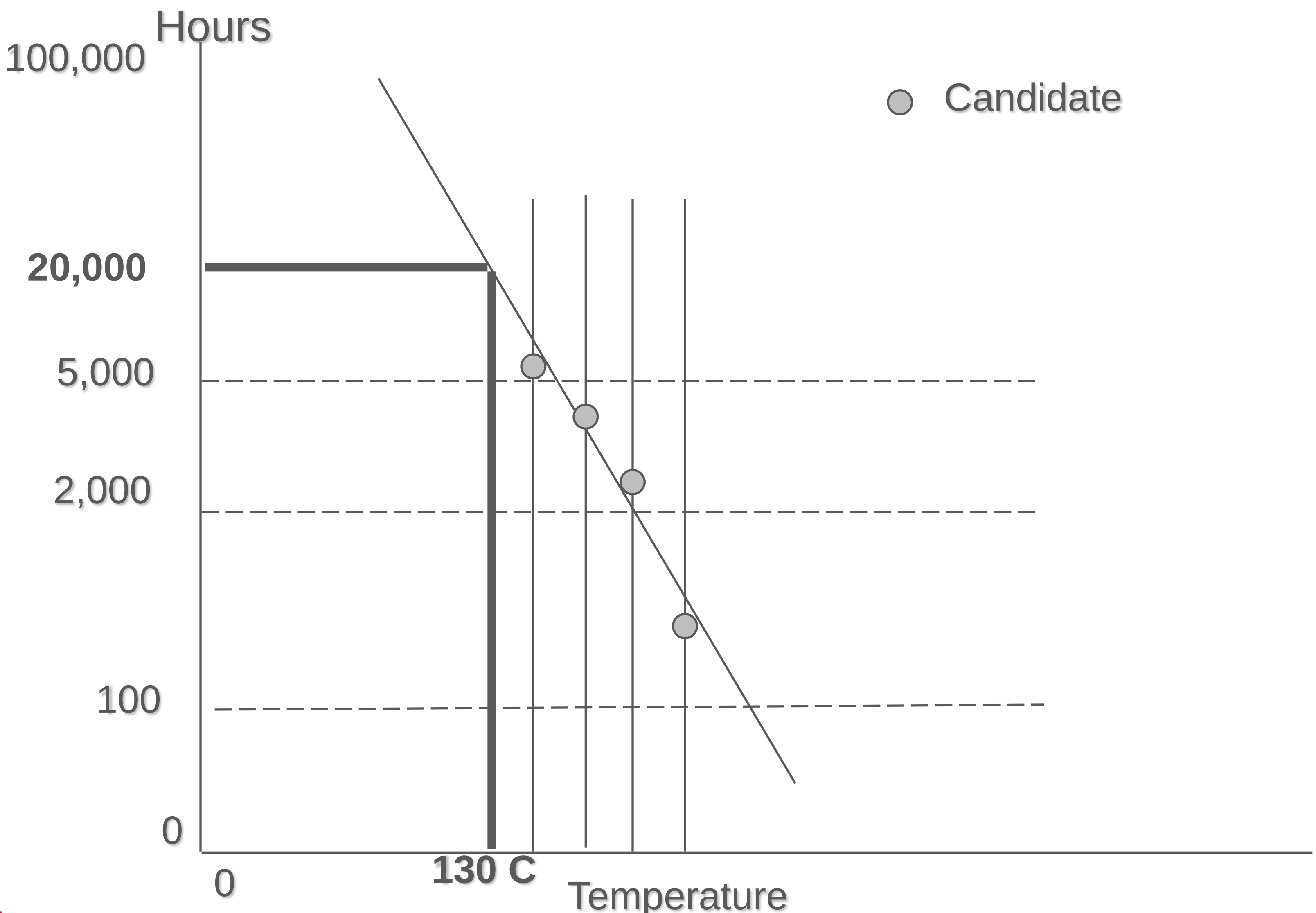
TI: IEC 60216-3 method does not incorporate control concept

- Correlation time is set at 20,000 hours

RTE: IEC 60216-5 (Fixed Temperature method)

IEC FDIS 60216-6 (Fixed Time method)

IEC 60216 Thermal Index



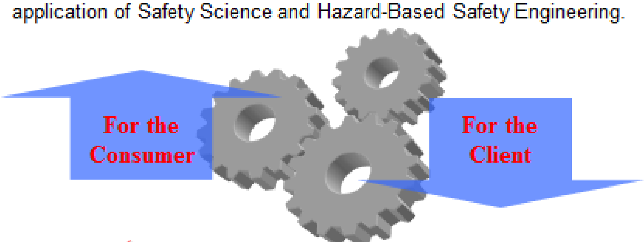
Thank You

Christopher Flueckiger
UL, LLC

Christopher.Flueckiger@UL.com

Our Mission:
Working for a Safer World Since 1894

To ***promote*** safe living and working environments for people by the application of Safety Science and Hazard-Based Safety Engineering.



To ***support*** the production and use of products which are physically and environmentally safe and to apply our efforts to prevent or reduce loss of life and property.