GSFC · 2015

Thermally Conductive Silicones for Space Applications

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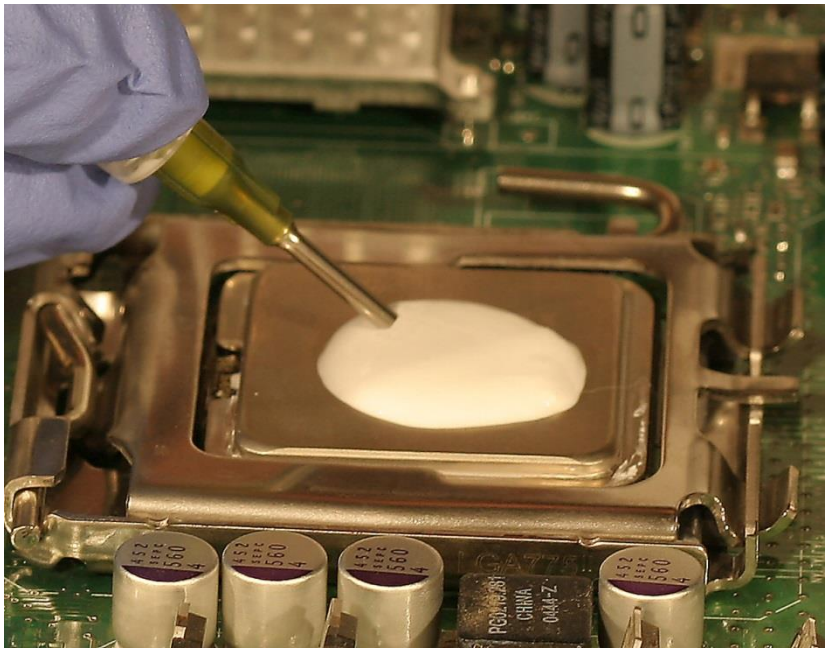
NuSil Technology

Learning Objectives

- Benefits of silicone elastomers
- Silicone composition & modification for use in extraterrestrial environments
- Trade offs on mechanical properties and viscosities of thermally conductive silicones
- Trends in product development

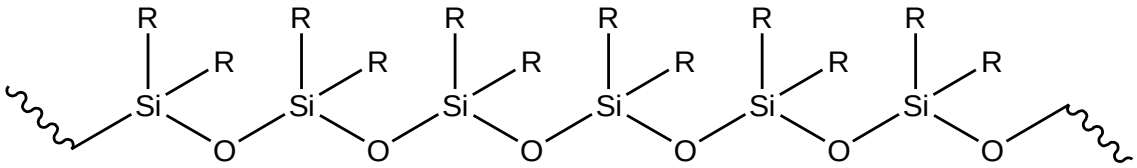


NuSil Facts

- NuSil is a global silicone manufacturer.
- Founded in 1979 Privately held since 1991
- 600+ employees
- Vertically integrated with multiple manufacturing facilities equipped to handle crisis management issues

Silicone is Unique

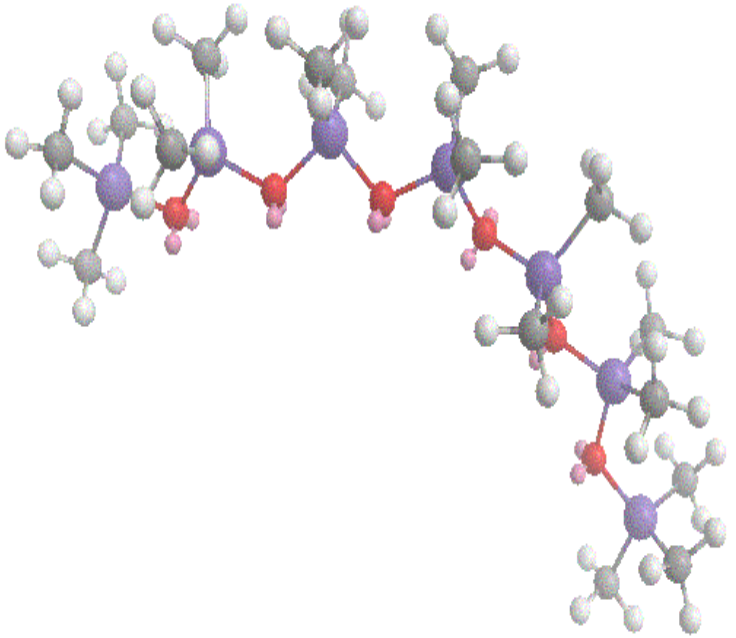
- A repeating backbone of linear siloxane units

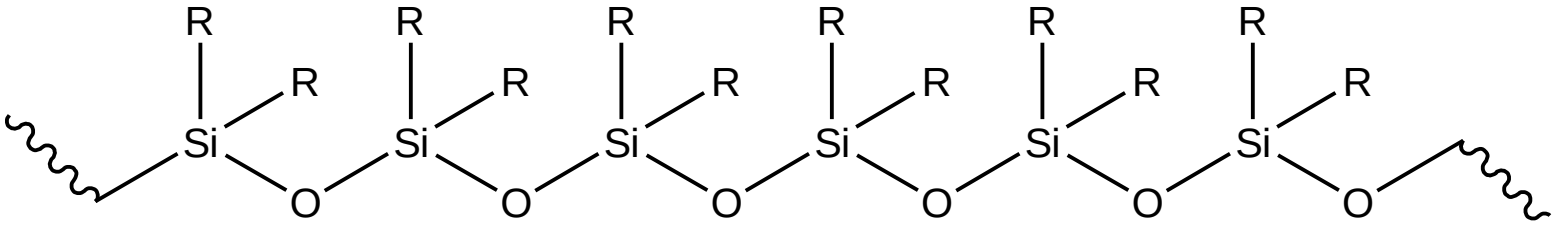


Typical Property	Epoxy C-C-C	Silicone Si-O-Si
Bond Lengths (nm)	0.154	0.164
Bond Angles	109^{o}	130 -150^{o}
Tg (oC)	> 80	< -60
CTE (ppm/oC)	45 – 100	40 - 450

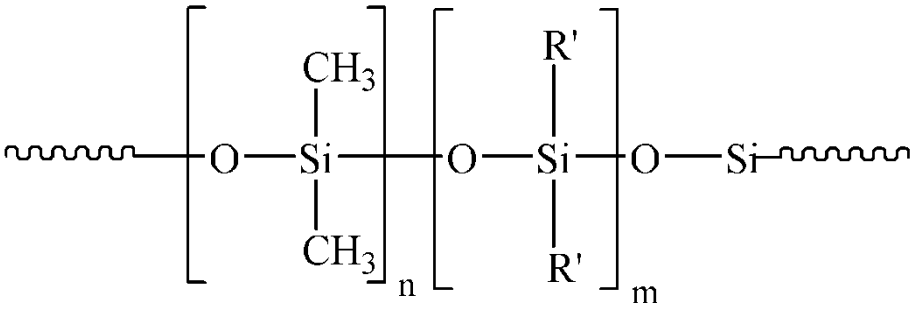
Silicone Polymer Characteristics

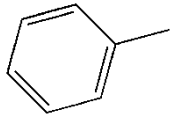
- Highly flexible chains
- Random coil configuration
- Large free volume
- Hydrophobic





Silicone Polymers Characteristics: R Groups



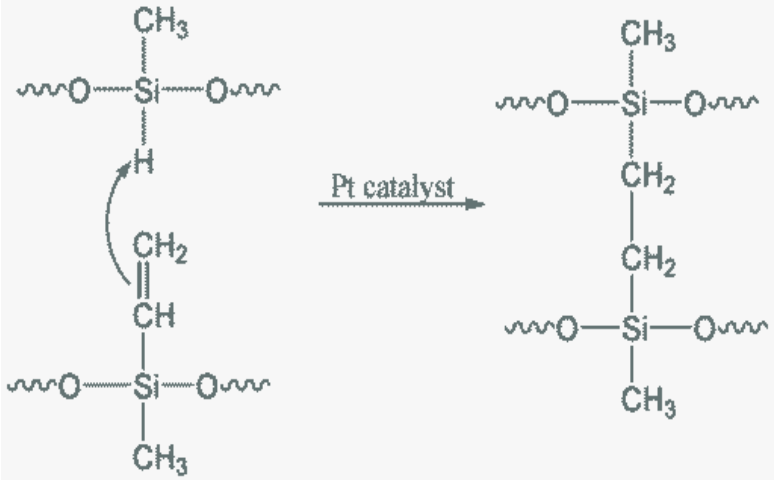
R' Group	Chemical and/or physical effects
Methyl (a.k.a. PDMS) CH_3-	Standard Refractive Index = 1.40 - Standard polymer Used industrially since 1950's
Trifluoropropyl (a.k.a Fluoro) F F-C- CH_2CH_2- F	Refractive Index = 1.38 or less Hydrocarbon solvent resistance
Phenyl 	Refractive Index = 1.43 or greater Increased temperature stability, reduces moisture permeability

Silicone Composition

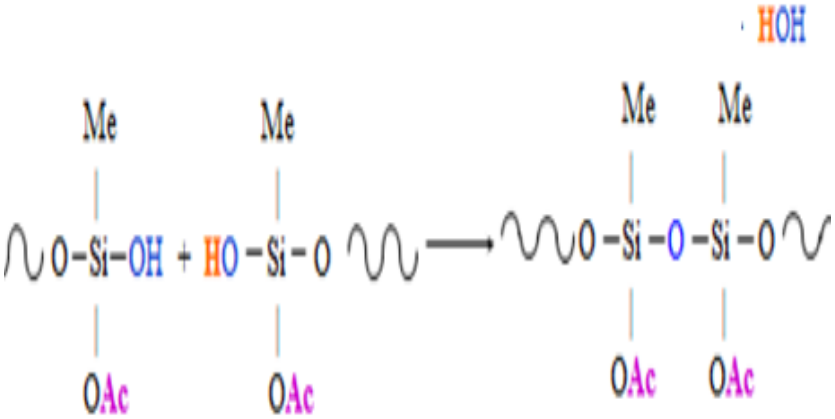
- Polymer
  - Makes up > 70 % (w/w) typical silicone formulation
  - Organic substituent group(s) can be varied.
  - Synthesis by Ring Opening Polymerization (ROP)
- “Base” - Increasing mechanical strength:
  - Add reinforcing additives to polymers to produce elastomers.
  - Silica and Resin are most common
- Curing
  - Platinum = Addition
  - Condensation
  - Peroxide

Main Cure Chemistries

- Addition Cure
  - Platinum Catalyst
  - Vinyl Functional polymer
  - Hydride polymer (crosslinker)
  - Inhibitor controls cure rate
  - Heat or Room Temp cure



- Condensation Cure
  - Contains hydrolyzable polymers
  - Needs moisture to cure
  - Releases water and leaving groups
  - Tin catalysts



Silicone Reinforcement

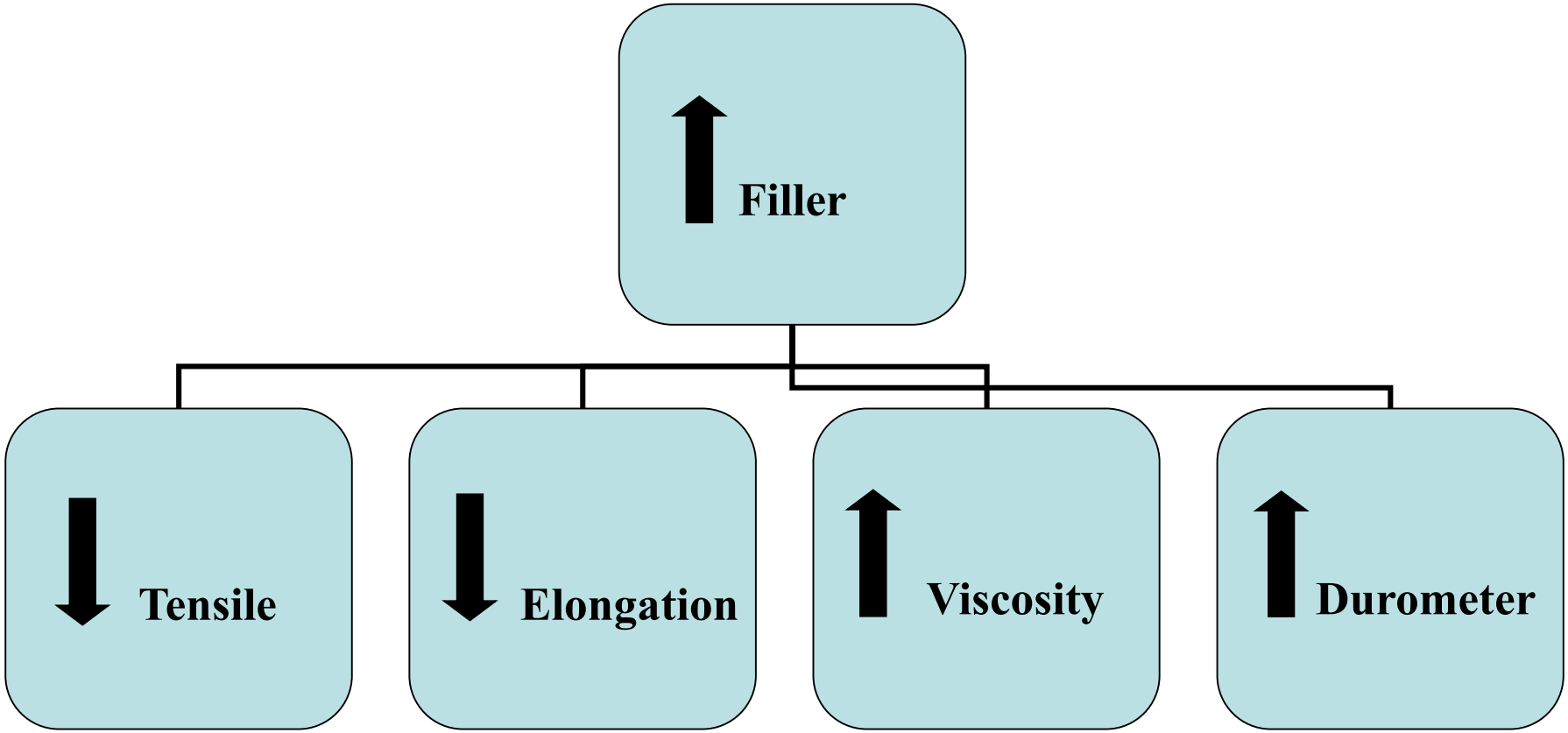
- Silicone Gels: Silicone polymers crosslinked together are soft with weak mechanical properties.

- Silicone Elastomers: Silicones reinforced with silica and/or silicone resin.
    - Silica Reinforcement:
        - Polymer-filler interaction (Van der Waals, Hydrogen bonding)
        - Viscosity of uncured silica filled silicones is affected - shear (“thixotropic”)
        - Translucent appearance

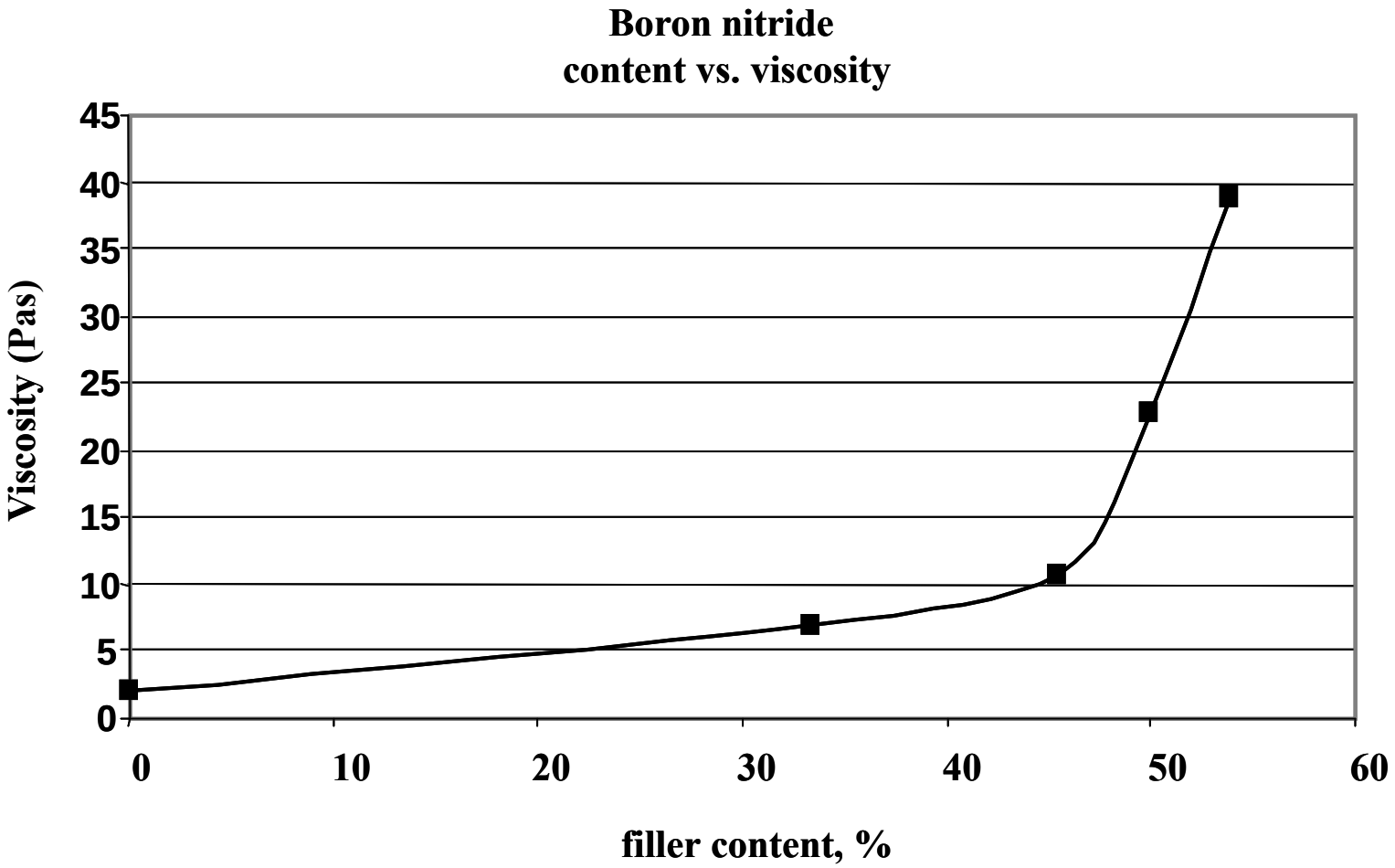
Functional Fillers

Properties	Fillers
Enhance Mechanical and Rheological Properties	Fumed Silica, Precipitated Silica
Increase Viscosity and Hardness	Ground Quartz, Diatomaceous Earth, Calcium Carbonate
Coloration	Pigments, Dyes
Radio Opacity, Blocks X-Rays	Barium Sulfate ($BaSO_4$)
Reduce Density	Microballoons
Thermal Stability	Iron Oxide, ZnO, TiO_2
Thermally Conductive	Boron Nitride, Aluminum Oxide
Electrically Conductive	Silver, Gold, Carbon Black

Typical Filler Effects

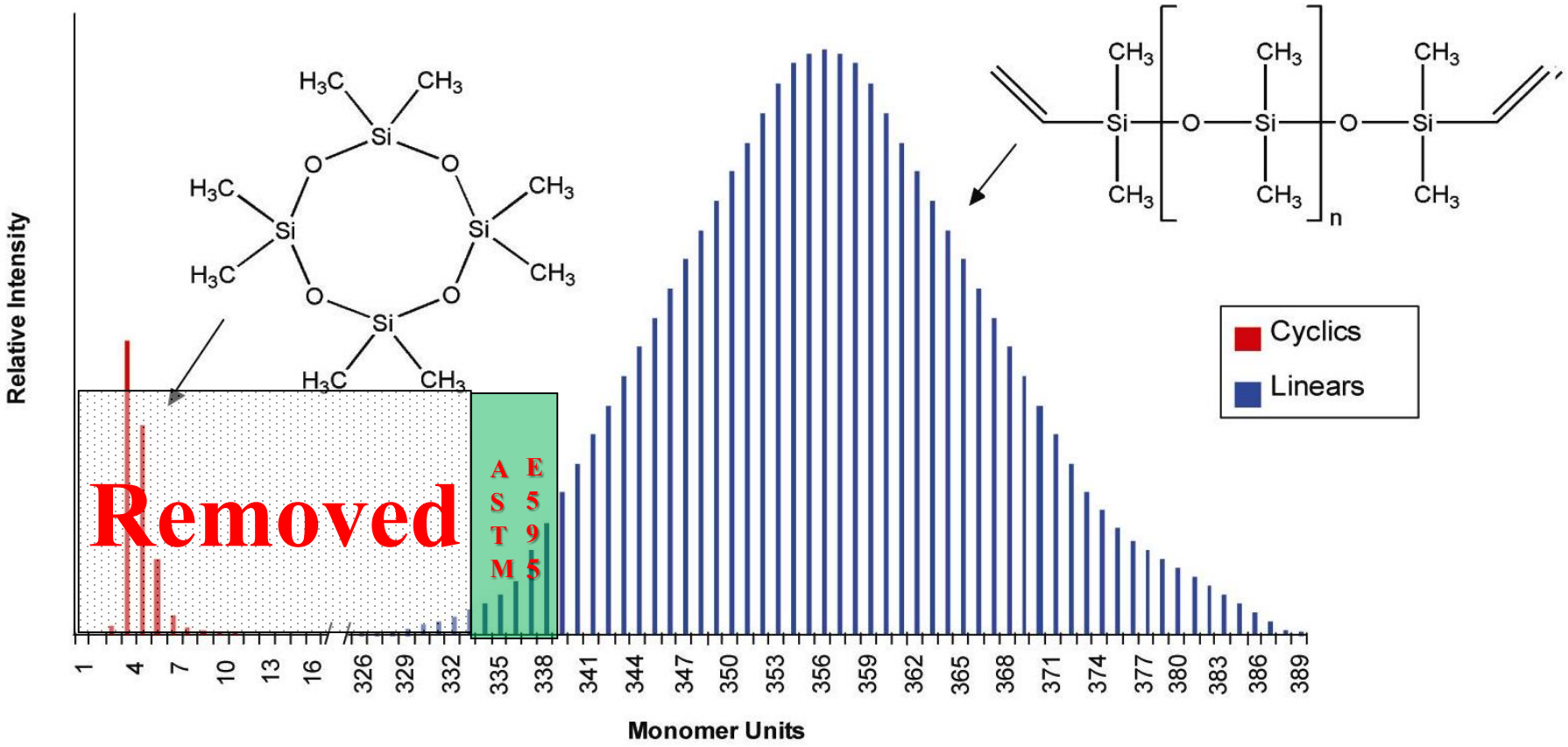


Viscosity Effects



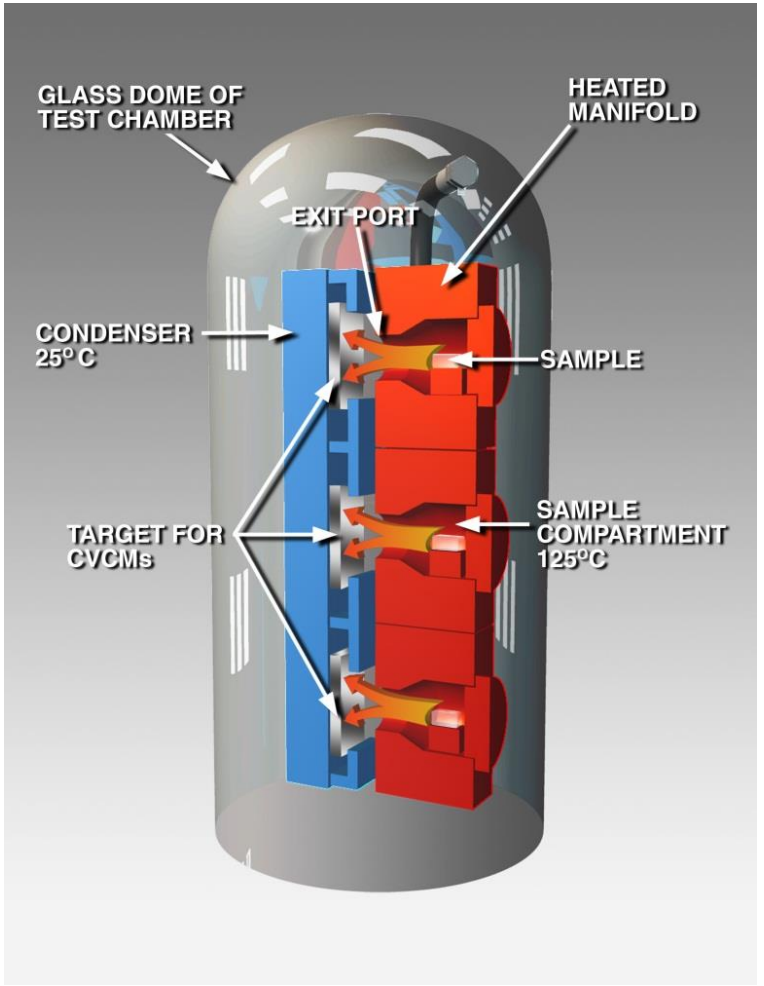
Ring Opening Polymerization (ROP)

- Thermodynamic Equilibrium results in a distribution of linear polymers varying in molecular weight plus cyclics.



Low Outgas Testing: ASTM E 595

- 125 °C @ $5x10^{-4}$ torr for 24 hours
- Test evaluates changes in mass
  - ≤ 1.0% Total Mass Loss (TML)
- Volatile species collect on condenser plate (25 °C)
  - ≤ 0.1 % Collected Volatile Condensable Material (CVCM)

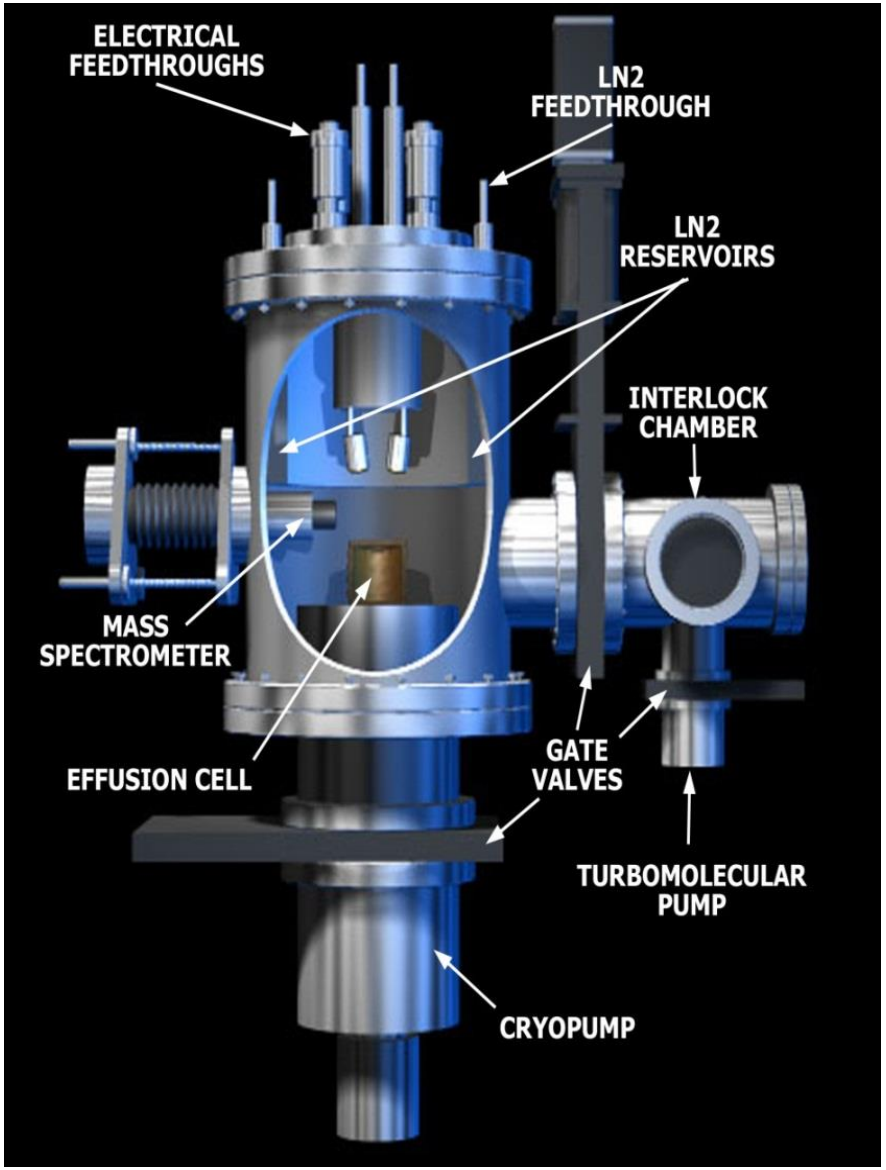


Ultra Low Outgassing™ Materials

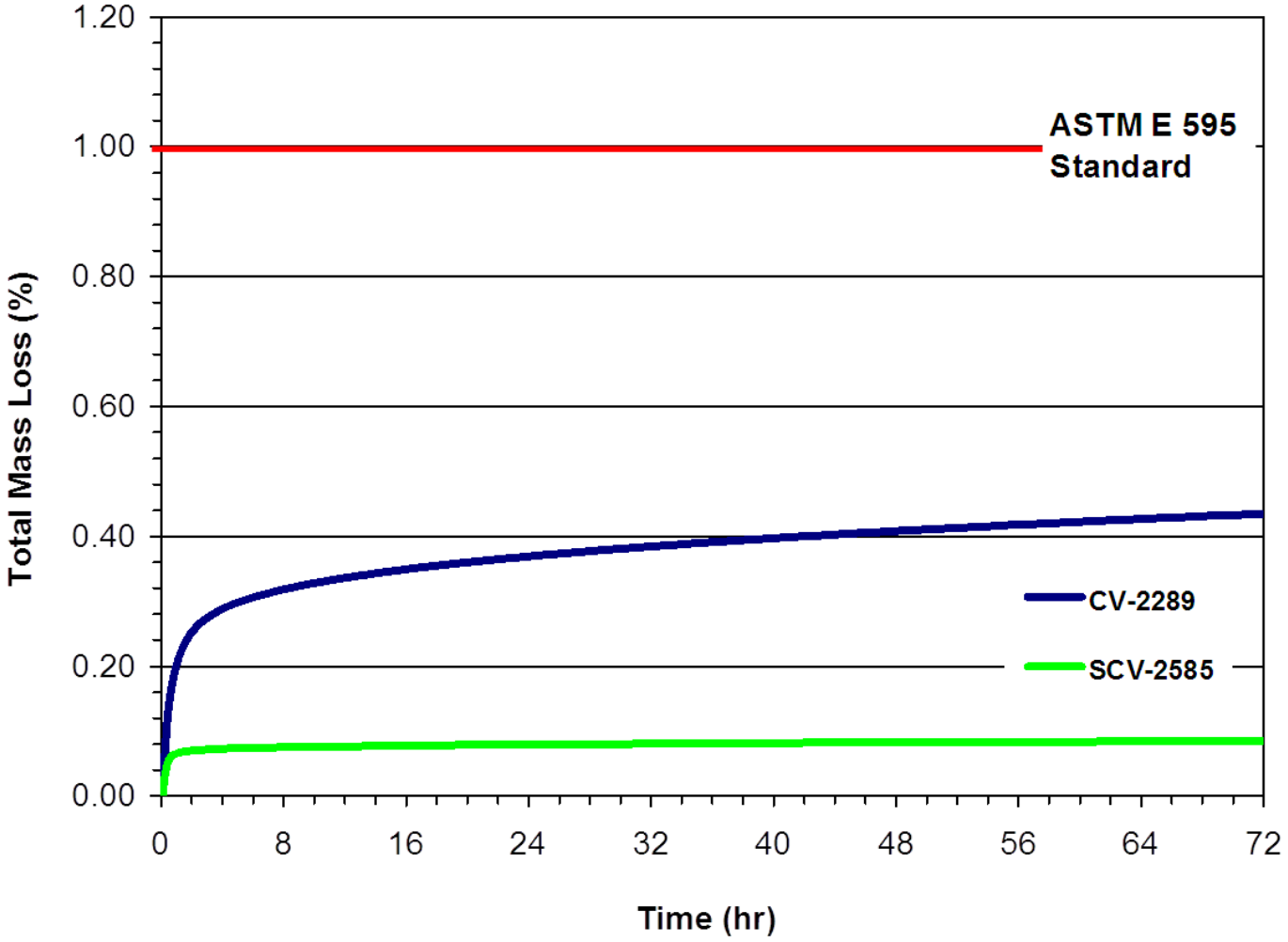
- Chosen by leading space programs to stand up to the most extreme conditions
- How we define Ultra Low Outgassing™ by utilizing ASTM E 595
  - ≤ 0.10% TML & ≤ 0.01% CVCM
  - Order of magnitude lower than traditional CV materials
  - Lower values result in extended operation life and greater reliability
- ASTM E 1559 screen tested

ASTM E 1559 Testing

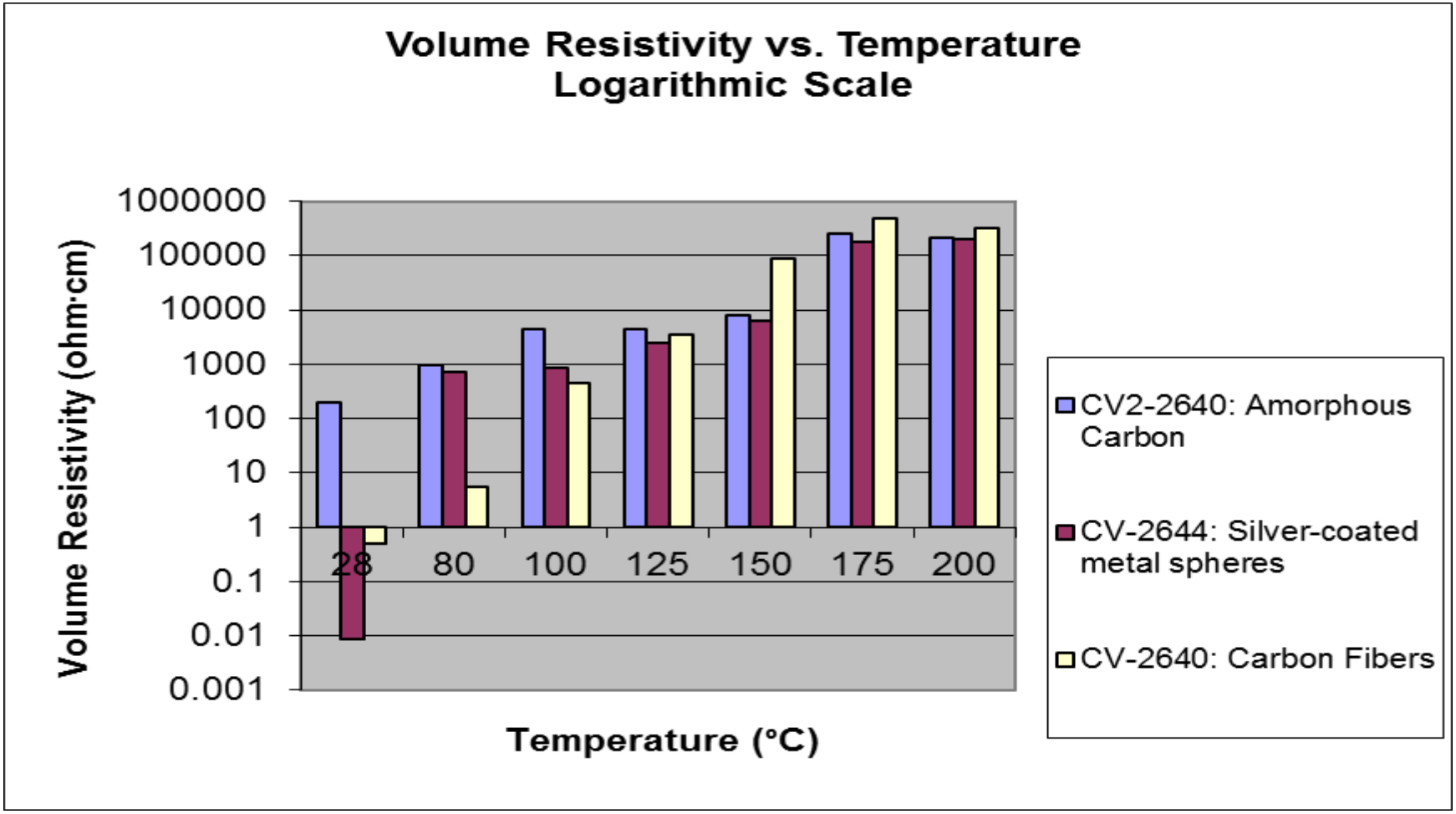
- Uses quartz crystal microbalance collection measurement approach (QCM)
- Characterizes the kinetics of the release of outgassing volatiles
- Qualitatively evaluates the released volatiles using Mass Spectrometry
- Compliments ASTM E 595 testing



ASTM E 1559:% Total Mass Loss Over Time



Volume Resistivity Versus Temperature



Thermal Conductivity at Various Temperatures

	GSFC Measurements (W/mK)*							
Product Name	**-150°C (±10%)**	**-100°C (±10%)**	**-50 °C (±10%)**	**0°C (±10%)**	**25°C (±10%)**	**50°C (±10%)**	**100°C (±10%)**	**Other Temperatures**
CV-2942	0.66	0.82	1.10	0.99	0.94	0.89	0.80	
CV-2943	1.27	1.53	1.56	1.47	1.38	1.29	1.18	
CV-2946	1.06	1.51	2.14	1.97	1.88	1.76	1.58	1.45 at 150°C
CV-2948	1.47	1.94	2.09	1.98	1.88	1.80	1.61	1.27 at 200°C
CV-2960	0.45	0.60	0.75	0.66	0.64	0.60	0.56	

*** Data published by the Materials Engineering Branch of NASA in Technical Information Paper (TIP) No. 119: Use of Thermally Conductive Potting/Staking Compounds"**

Filled Silicone Types

- Fillers can be incorporated in a variety of formats:
  - Cured Thermal Pads
  - Uncured Calendered Sheeting
  - Liquid Adhesives
    - Smooth Pastes

NuSil What's Next?

- Thermal pads, PSAs, and film adhesives can solve some of the problems associated with liquid adhesives:
  - Mixing & De-airing
  - Cure inhibition
  - Short work times
  - Long cure times
- Thermal pads, PSAs, and film adhesives can offer a peel-and-stick option for bonding substrates.

Conclusions

- Processing constraints, component conditions and weight of modified silicones must be considered.
- Advances in functional fillers and silicone offer significant property benefits.
- The degree of conductivity can be controlled and maintained even in harsh environments.
- Thermal pads, PSAs, and film adhesives offer process efficient improvements.

Your Partner of Choice

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