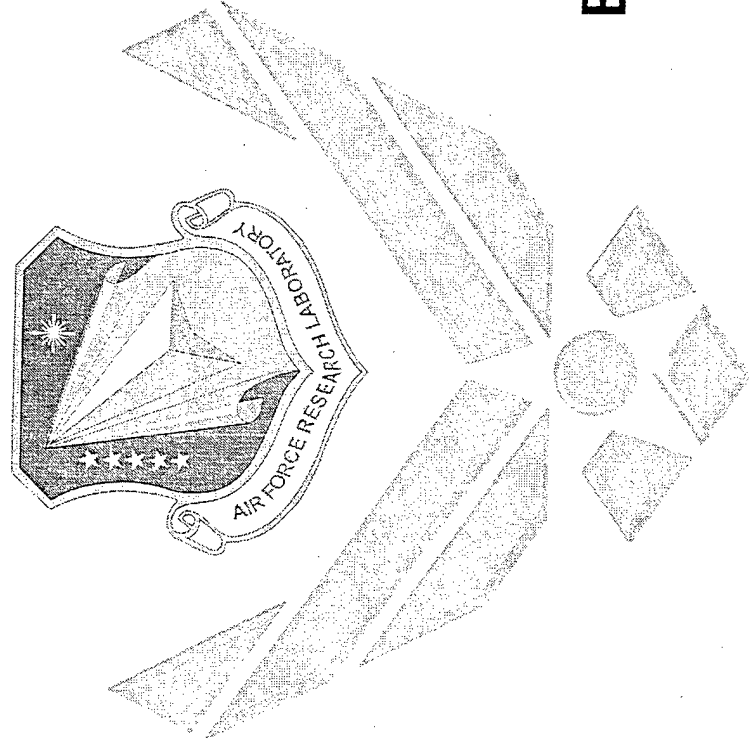


| <b>REPORT DOCUMENTATION PAGE</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                    |                                                       |                                   | Form Approved<br>OMB No. 0704-0188                               |                                                                    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-------------------------------------------------------|-----------------------------------|------------------------------------------------------------------|--------------------------------------------------------------------|
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. <b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b> |                                    |                                                       |                                   |                                                                  |                                                                    |
| <b>1. REPORT DATE (DD-MM-YYYY)</b><br>03-29-2004                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                    | <b>2. REPORT TYPE</b><br>Technical Paper (View Graph) |                                   | <b>3. DATES COVERED (From - To)</b>                              |                                                                    |
| <b>4. TITLE AND SUBTITLE</b><br><br>Fluorinated Polyhedral Oligomeric Silsesquioxanes (FluoroPOSS)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                                       |                                   | <b>5a. CONTRACT NUMBER</b><br>F04611-99-C-0025                   |                                                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                                       |                                   | <b>5b. GRANT NUMBER</b>                                          |                                                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                                       |                                   | <b>5c. PROGRAM ELEMENT NUMBER</b>                                |                                                                    |
| <b>6. AUTHOR(S)</b><br><br>J. M. Mabry, A. Vij, D. Marchant, B. D. Viers, P. N. Ruth, C. E. Schlaefer                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                    |                                                       |                                   | <b>5d. PROJECT NUMBER</b><br>2303                                |                                                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                                       |                                   | <b>5e. TASK NUMBER</b><br>M1A3                                   |                                                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                                       |                                   | <b>5f. WORK UNIT NUMBER</b>                                      |                                                                    |
| <b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b><br><br>ERC Incorporated<br>555 Sparkman Drive<br>Huntsville, AL 35816-0000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                                       |                                   | <b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>                  |                                                                    |
| <b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b><br><br>Air Force Research Laboratory (AFMC)<br>AFRL/PRSB<br>4 Draco Drive<br>Edwards AFB CA 93524-7160                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                    |                                                       |                                   | <b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>                          |                                                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                                       |                                   | <b>11. SPONSOR/MONITOR'S NUMBER(S)</b><br>AFRL-PR-ED-VG-2004-102 |                                                                    |
| <b>12. DISTRIBUTION / AVAILABILITY STATEMENT</b><br><br>Approved for public release; distribution unlimited.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                    |                                                       |                                   |                                                                  |                                                                    |
| <b>13. SUPPLEMENTARY NOTES</b><br>American Chemical Society Meeting<br>Anaheim, CA, 1 April 2004                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                    |                                                       |                                   |                                                                  |                                                                    |
| <b>14. ABSTRACT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                    |                                                       |                                   |                                                                  |                                                                    |
| 20040503 191                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                    |                                                       |                                   |                                                                  |                                                                    |
| <b>15. SUBJECT TERMS</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                    |                                                       |                                   |                                                                  |                                                                    |
| <b>16. SECURITY CLASSIFICATION OF:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                    |                                                       | <b>17. LIMITATION OF ABSTRACT</b> | <b>18. NUMBER OF PAGES</b>                                       | <b>19a. NAME OF RESPONSIBLE PERSON</b>                             |
| <b>a. REPORT</b><br>Unclassified                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>b. ABSTRACT</b><br>Unclassified | <b>c. THIS PAGE</b><br>Unclassified                   | A                                 | 54                                                               | Linda Talon                                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                                       |                                   |                                                                  | <b>19b. TELEPHONE NUMBER (include area code)</b><br>(661) 275-5865 |

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# Fluorinated Polyhedral Oligomeric Silsesquioxanes (FluoroPOSS)

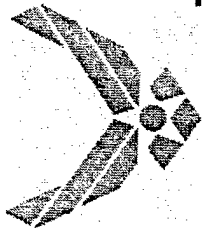


*Silicones and Silicone-  
Modified Materials*

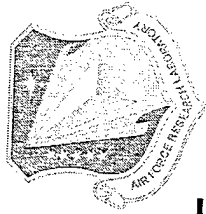
*April 1, 2004*

JM Mabry, A Vij, D Marchant,  
BD Viers, PN Ruth, and CE Schlaefer  
Polymer Working Group  
Air Force Research Laboratory  
(661)275-5857

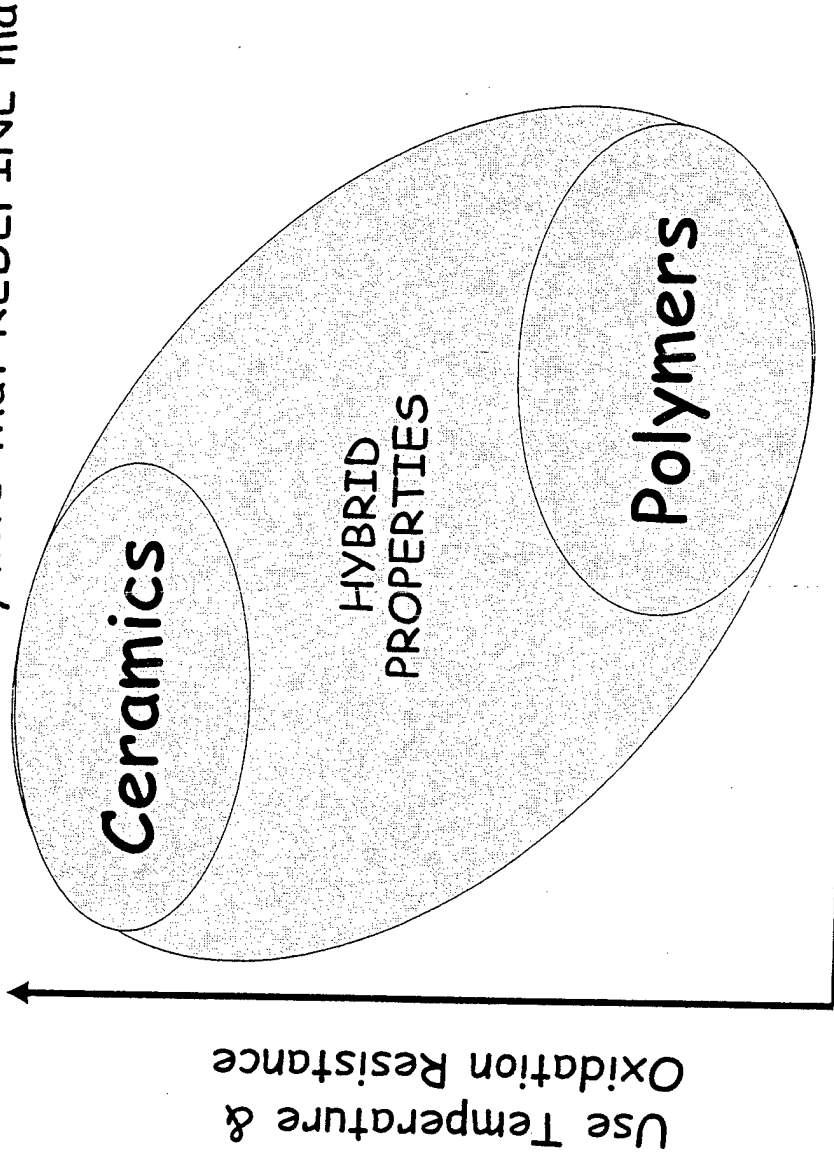
[joseph.mabry@edwards.af.mil](mailto:joseph.mabry@edwards.af.mil)



# Hybrid Inorganic/Organic Polymers



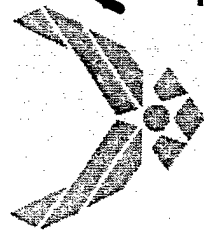
Goal: Develop High Performance Polymers that REDEFINE material properties



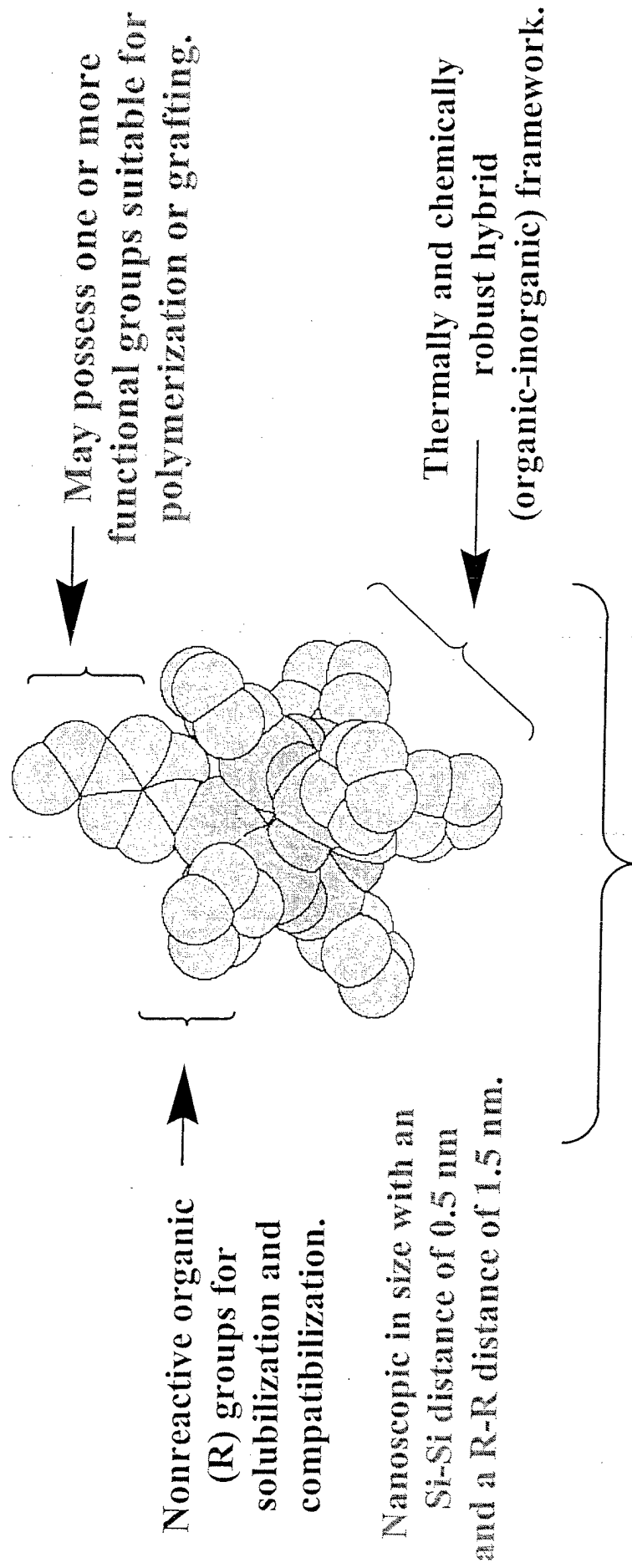
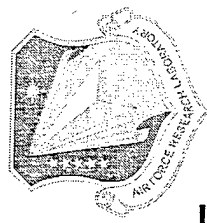
PAS-03-061

• Hybrid plastics bridge the differences between ceramics and polymers

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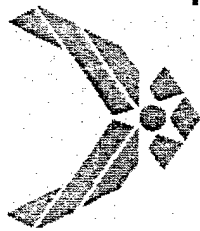
# Anatomy of a POSS Nanostructure



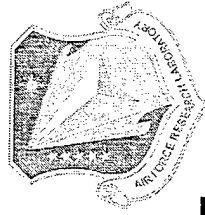
Precise three-dimensional structure for molecular level reinforcement of polymer segments and coils.

PAS-03-061

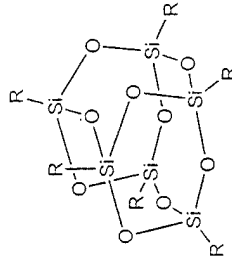
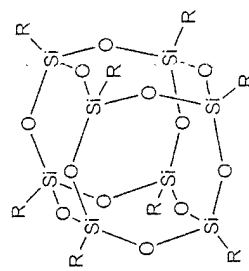
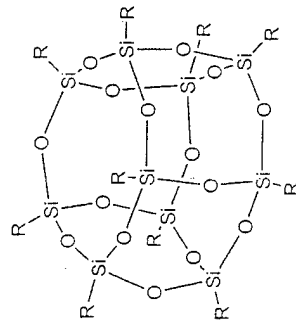
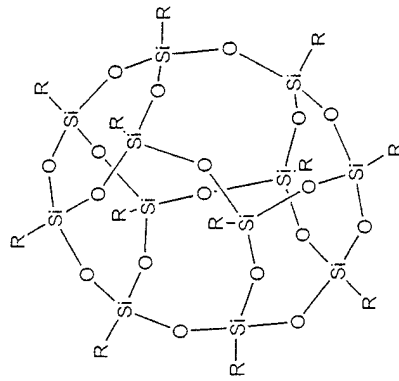
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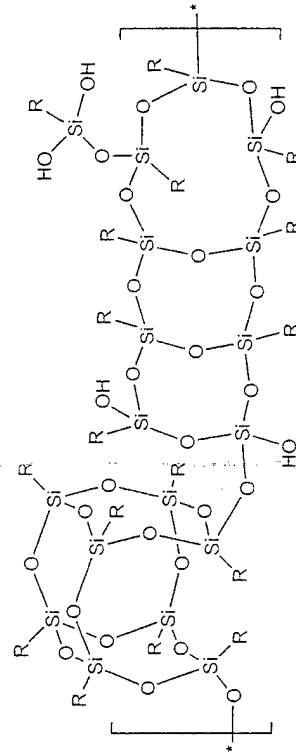
# POSS Synthesis



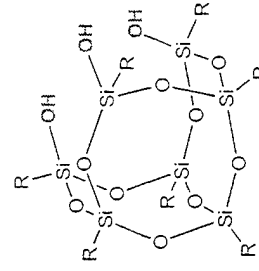
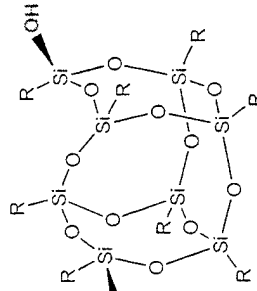
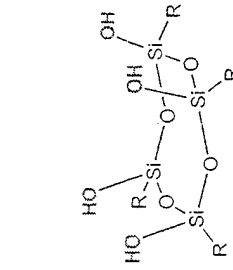
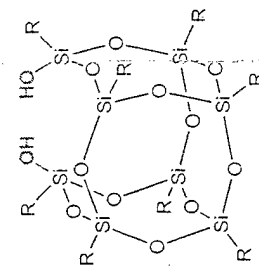
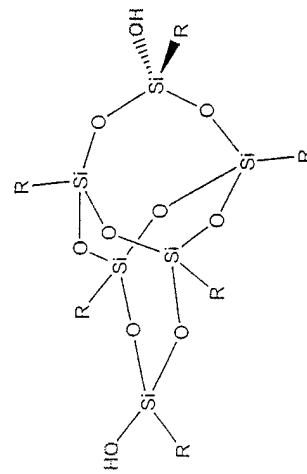
RSiX<sub>3</sub> acid or base hydrolysis



**Completely condensed**



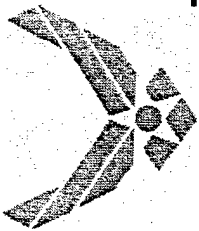
**Resin**



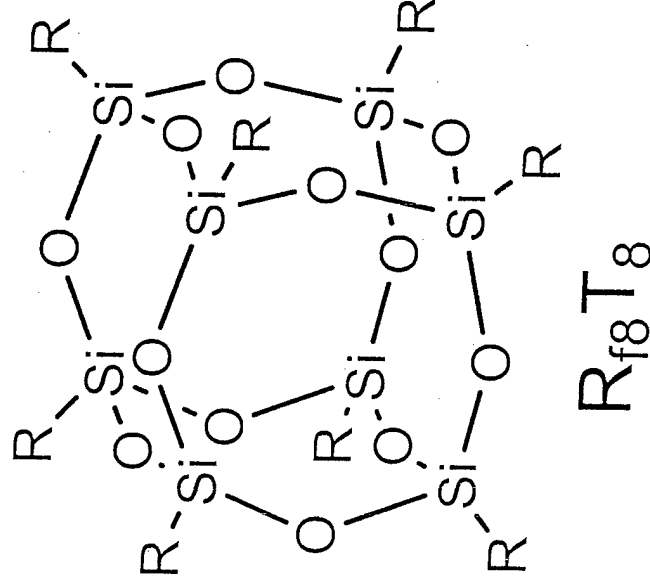
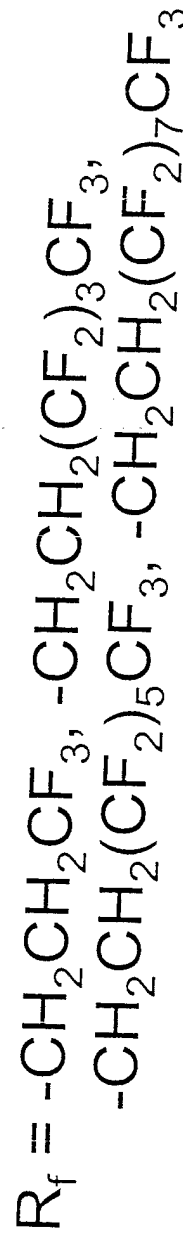
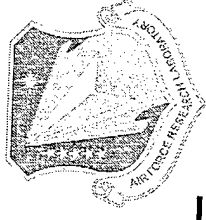
**Incompletely condensed**

**Brown, Feher, AFRL, Hybrid Plastics**

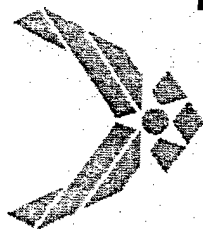
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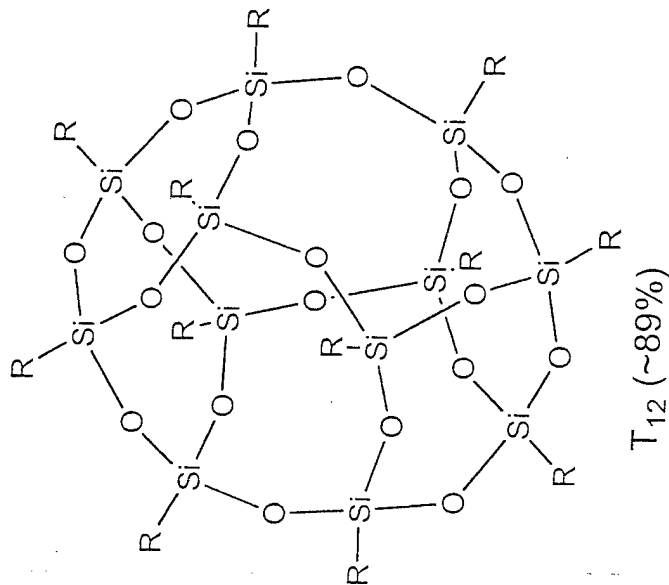
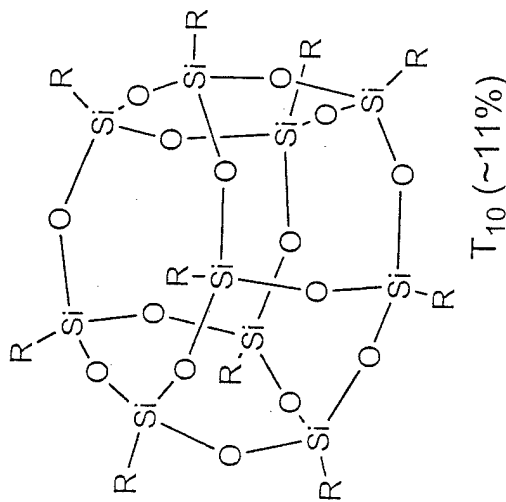
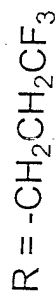
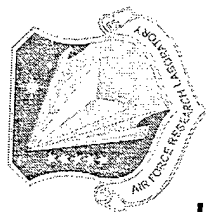
# FluoroPOSS Synthesis



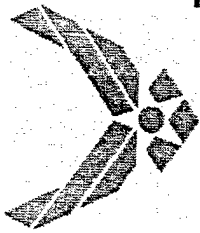
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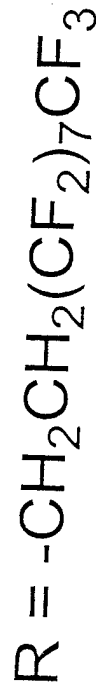
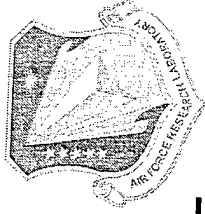
# Fluoropropyl $T_n$



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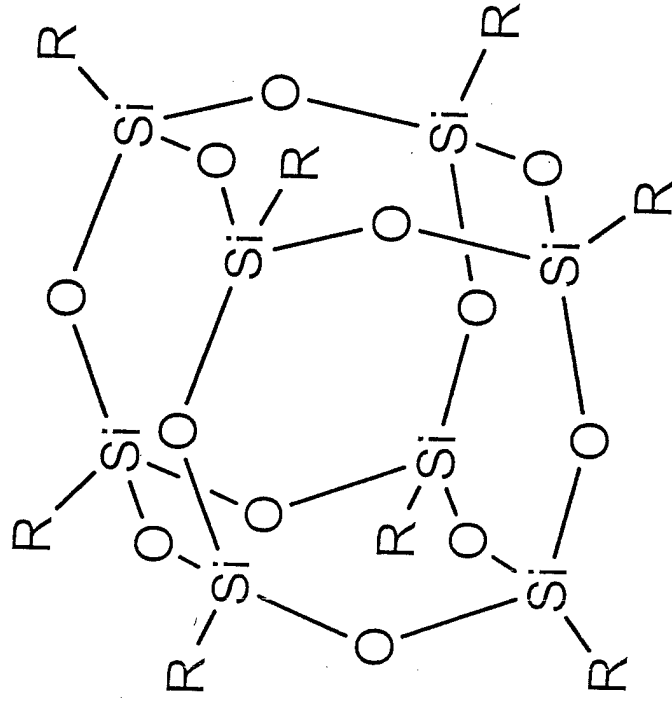


# Fluorodecyl<sub>8</sub>T<sub>8</sub>

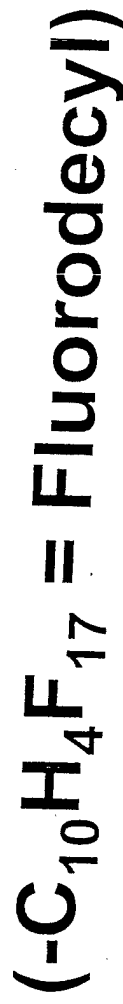


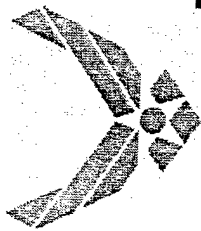
$$M_W = 3993.54 \text{ g/mol}$$

$$\rho = 2.058 \text{ g/mL}$$

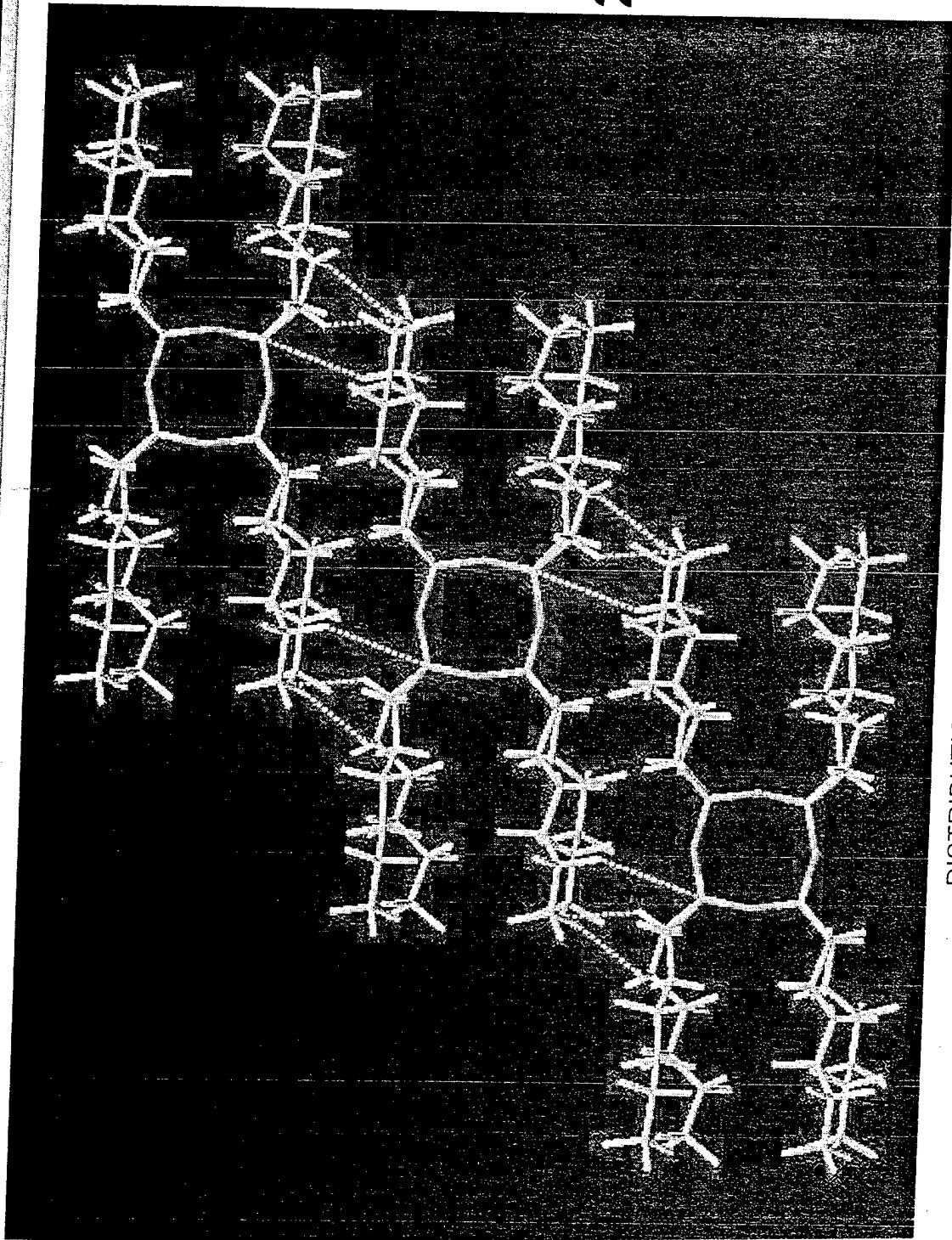
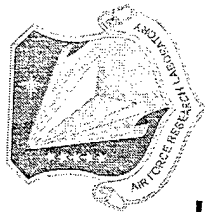


T<sub>8</sub>





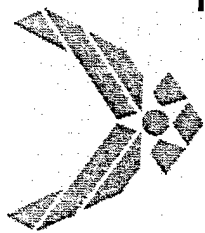
# Fluorohexyl<sub>8</sub>T<sub>8</sub>



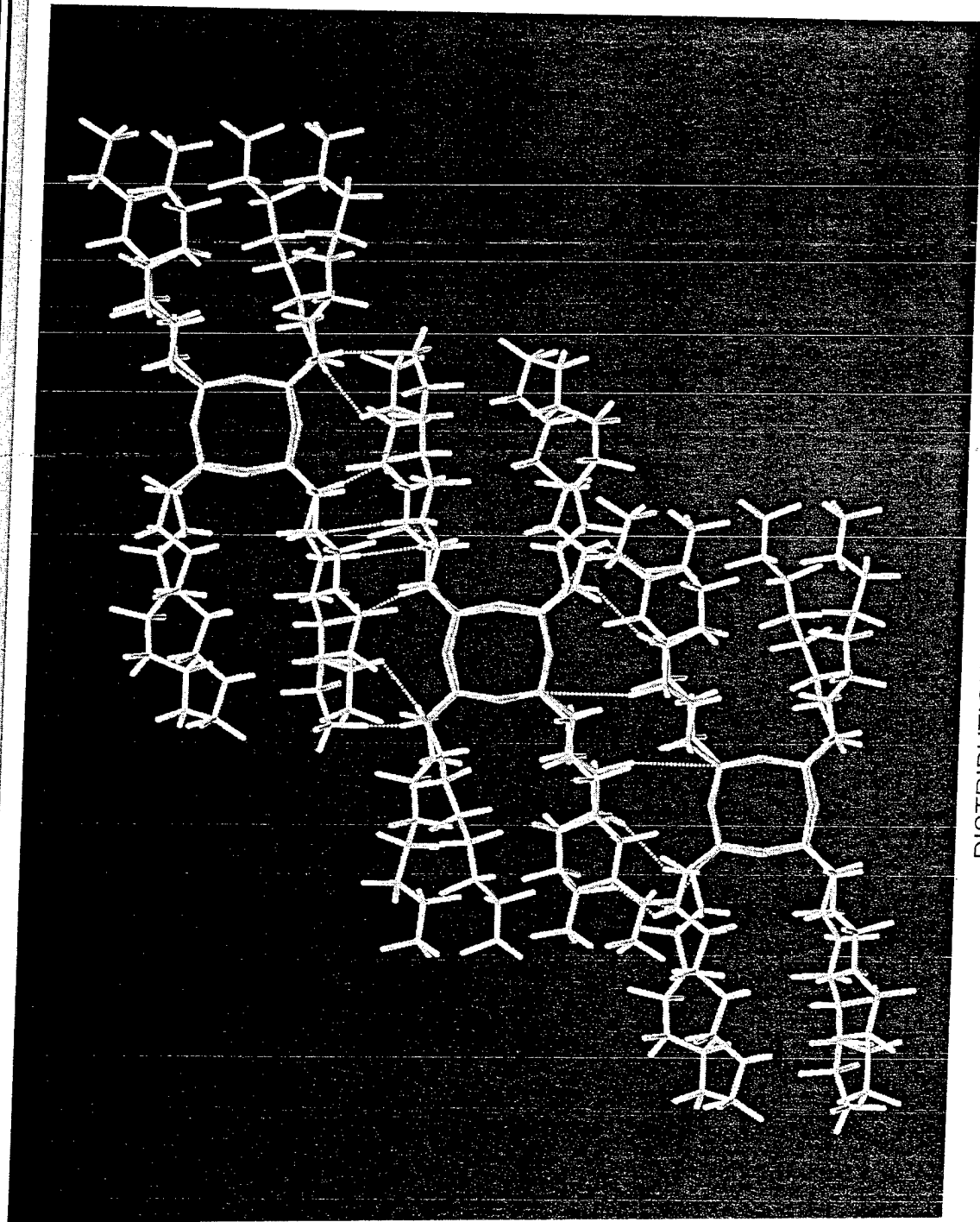
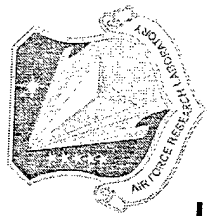
$$\rho = 1.98 \text{ g/mL}$$

$$M_w = 2393.33 \text{ g/mol}$$

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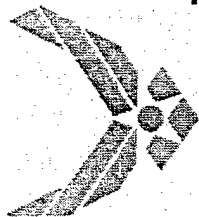
# Fluorooctyl<sub>8</sub>T<sub>8</sub>



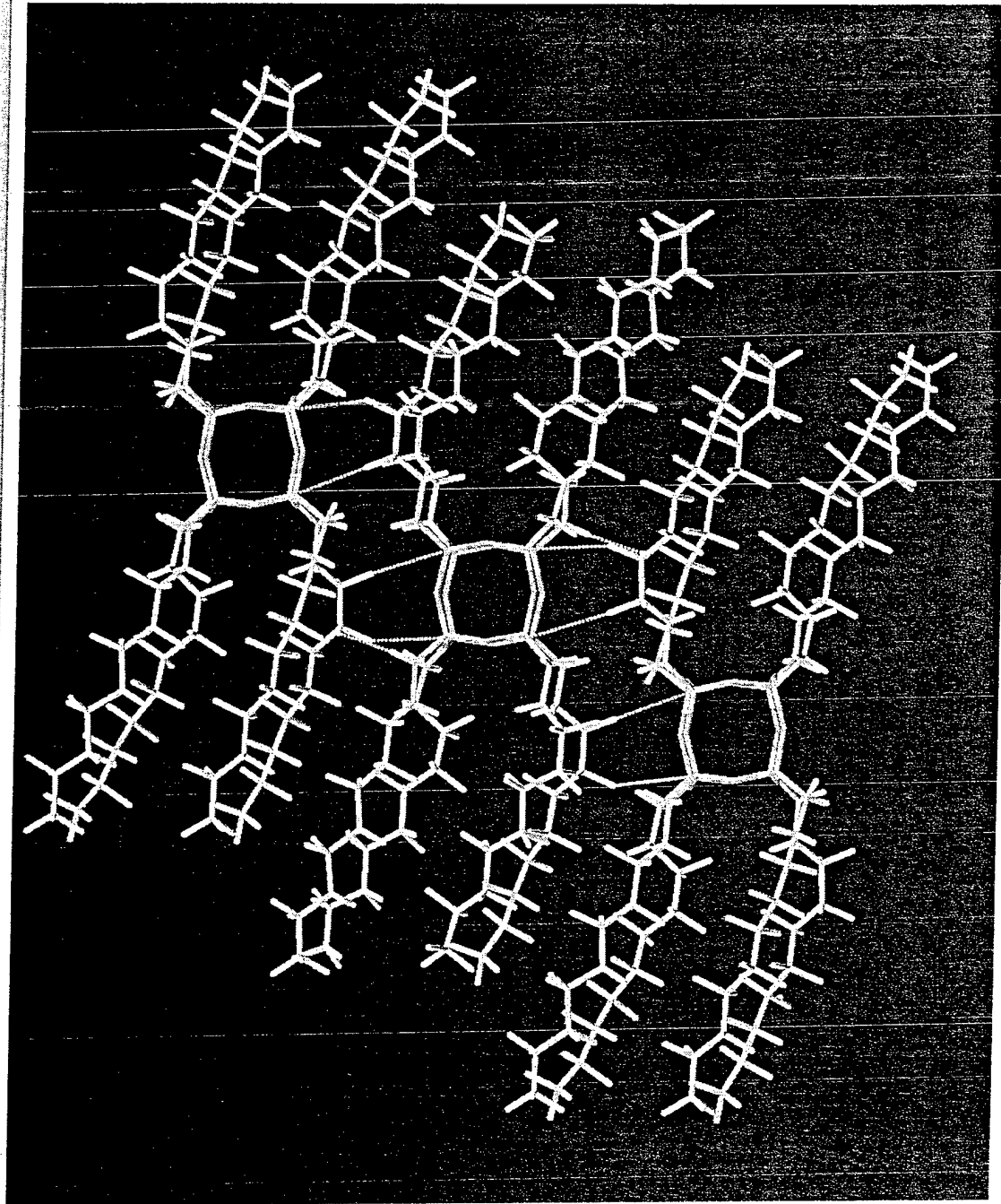
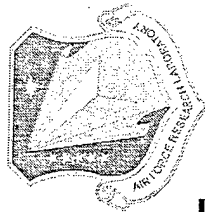
$$\rho = 2.05 \text{ g/mL}$$

$$M_w = 3193.45 \text{ g/mol}$$

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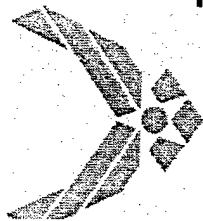
# Fluorodecyl<sub>8</sub>T<sub>8</sub>



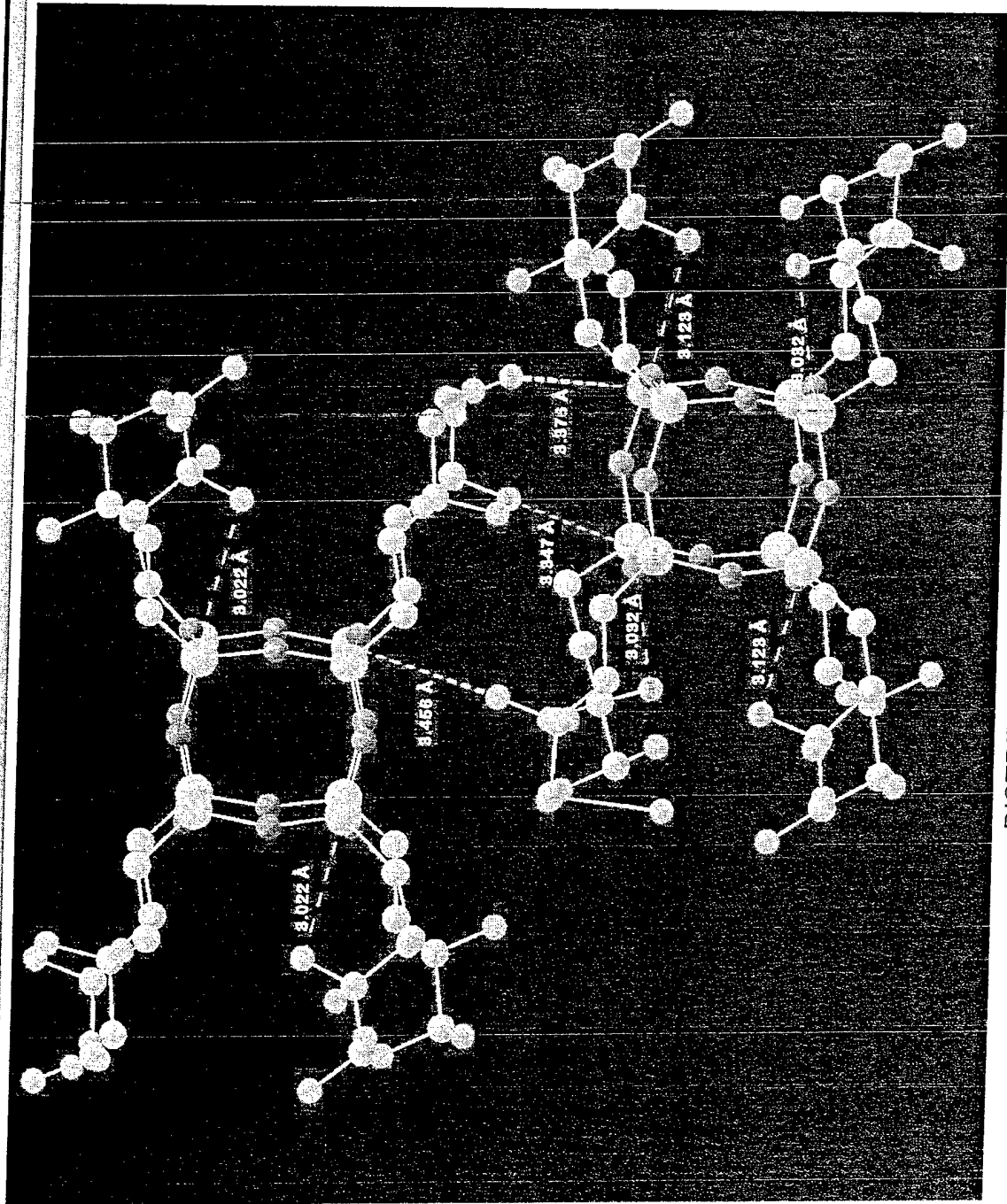
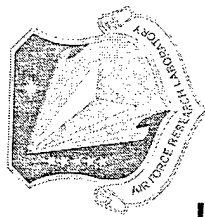
$$\rho = 2.06 \text{ g/mL}$$

$$M_w = 3993.54 \text{ g/mol}$$

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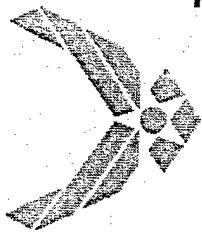


# Fluorodecyl<sub>8</sub>T<sub>8</sub>

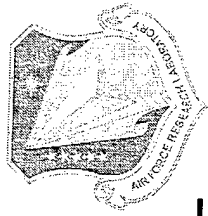


Inter- and intra-  
molecular Si-F  
contacts affect  
crystal packing

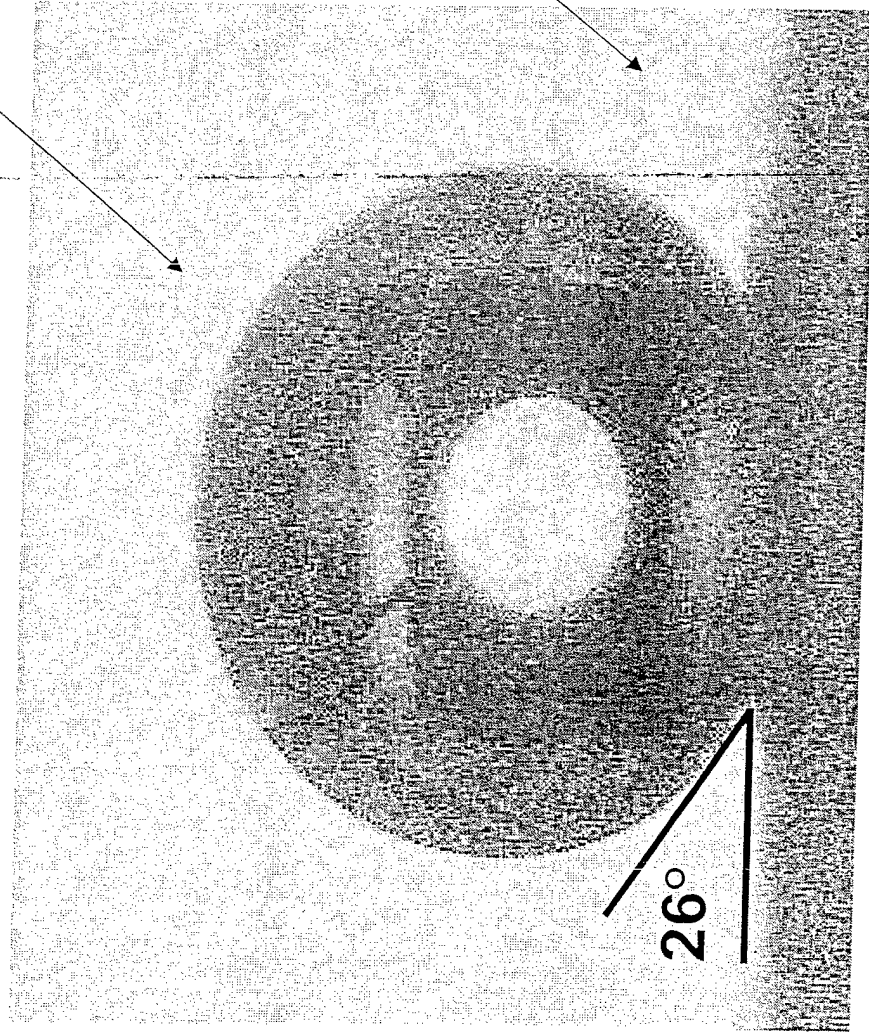
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# Contact Angle of Water on Fluorodecyl POSS Surface



Drop of  
 $H_2O$

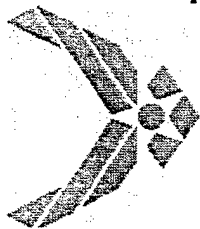


POSS  
Coated  
Surface

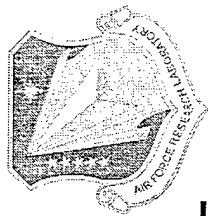
- Anti Icing surfaces
- Low Friction Surfaces

40° Higher than PTFE

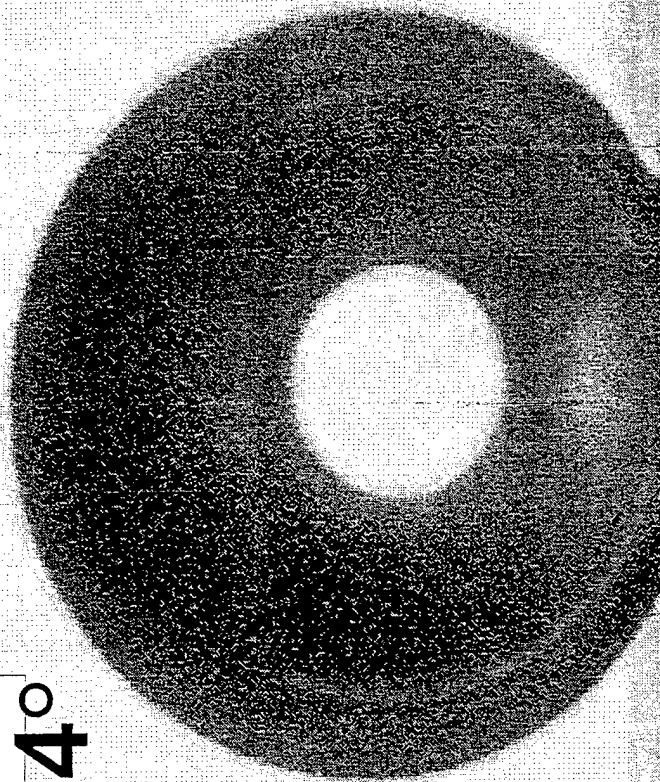
26°



# Contact Angle of Water on Fluorodecyl POSS Surface



154°

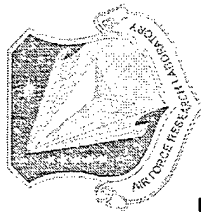


**40° Higher than PTFE**

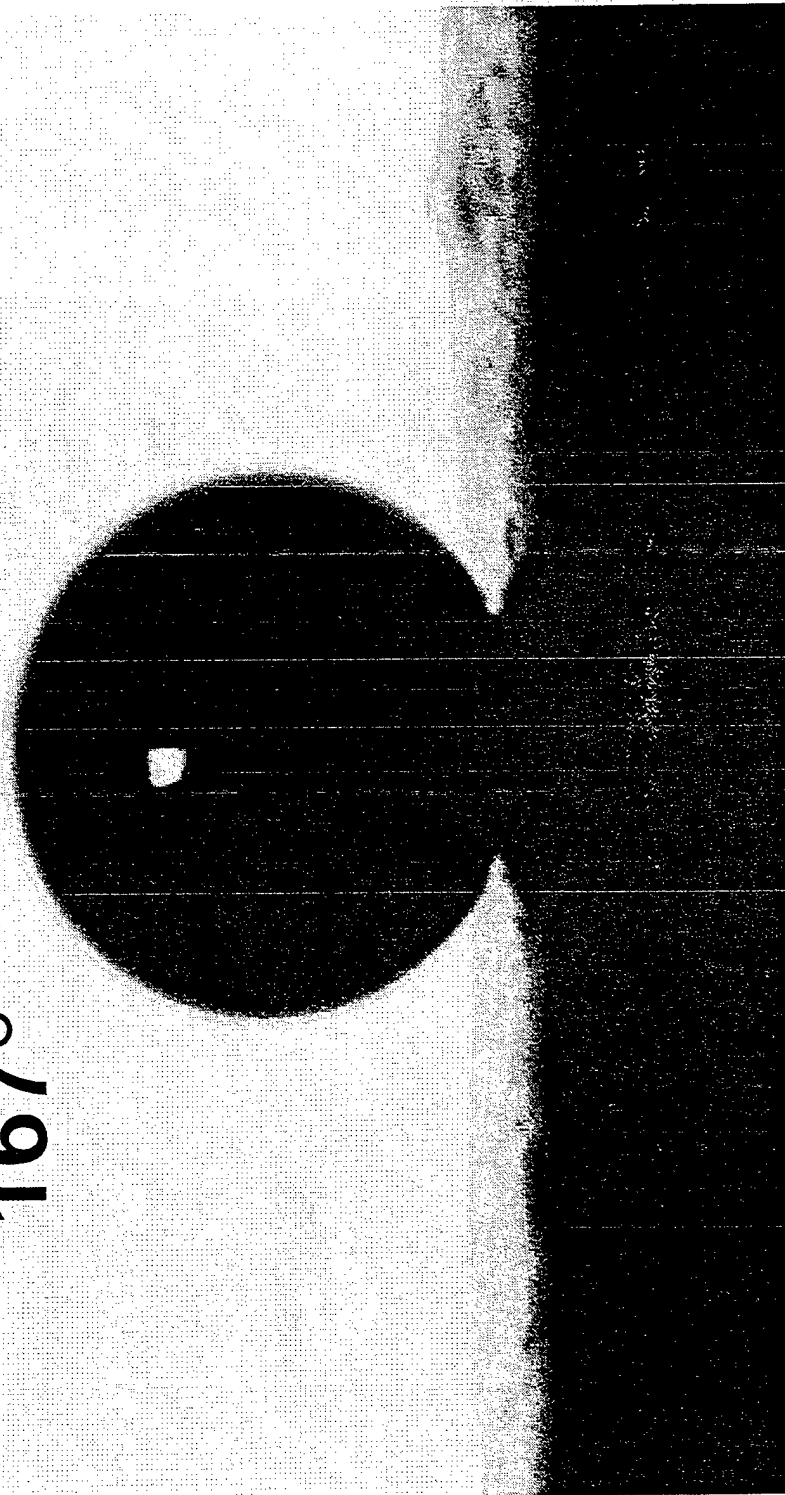
DISTRIBUTION A. Approved for public release; distribution unlimited.



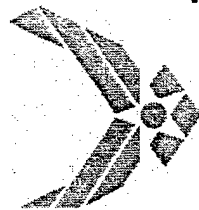
# Contact Angle of Mercury on Fluorodecyl POSS Surface



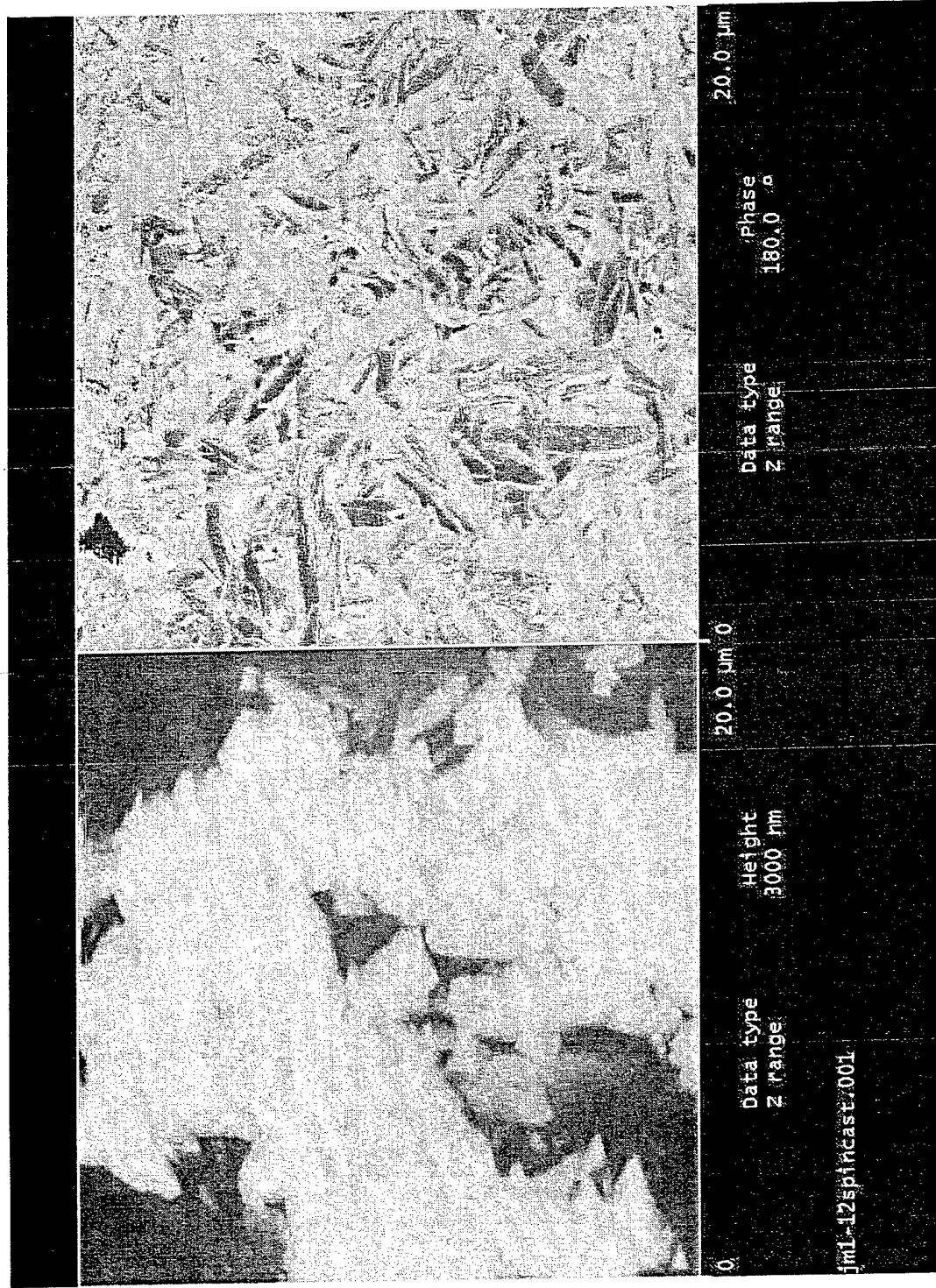
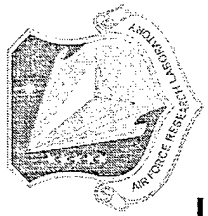
167°



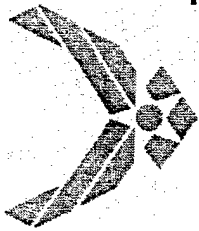
DISTRIBUTION A. Approved for public release; distribution unlimited.



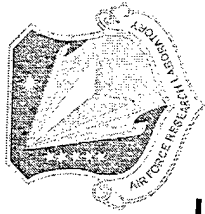
# AFM Image of Spin-Cast Fluorodecyl<sub>18</sub>T<sub>8</sub> Surface



DISTRIBUTION A. Approved for public release; distribution unlimited.



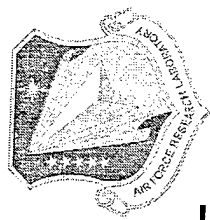
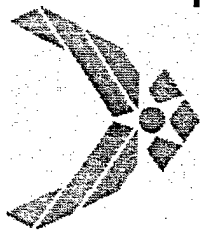
# Surface Energy of Fluorosiloxanes



| <u>Polymer</u>                           | <u>Surface Energy (mJ/m<sup>2</sup>)</u> |
|------------------------------------------|------------------------------------------|
| Poly(methylheptadecafluorodecylsiloxane) | 7.0                                      |
| Poly(methylnonafluorohexylsiloxane)      | 9.5                                      |
| Poly(methyltrifluoropropylsiloxane)      | 13.6                                     |
| Poly(dimethylsiloxane) (PDMS)            | 22.8                                     |
| Poly(tetrafluoroethylene) (PTFE)         | 19.1                                     |

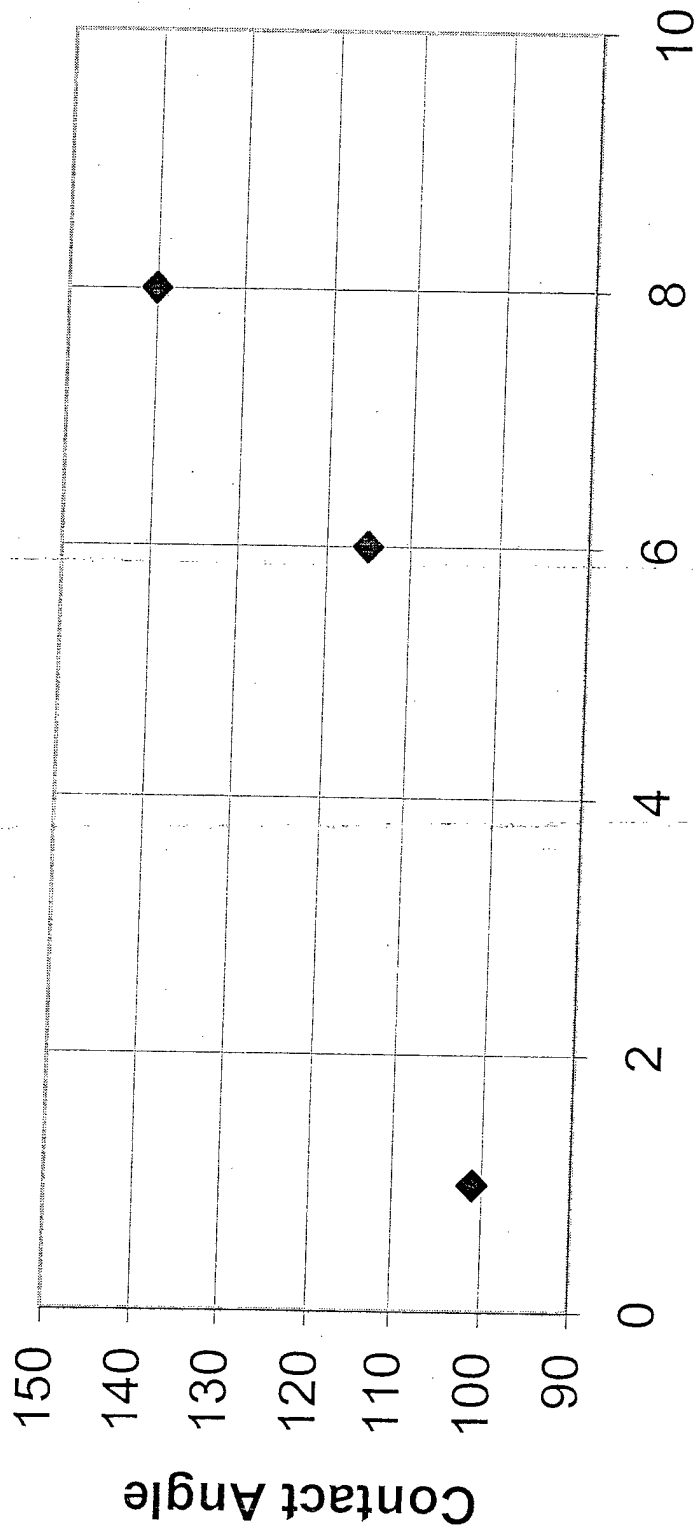
Maxson, M. T.; Norris, A. W.; Owen, M. J. "Fluorosilicones" In "Modern Fluoropolymers"; Scheirs, J. Ed.; J. Wiley & Sons: New York, 1997, pp 359-372.

DISTRIBUTION A. Approved for public release; distribution unlimited.

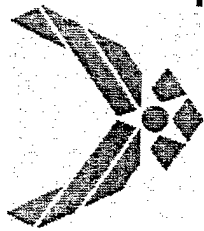


# Contact Angle and Chain Length

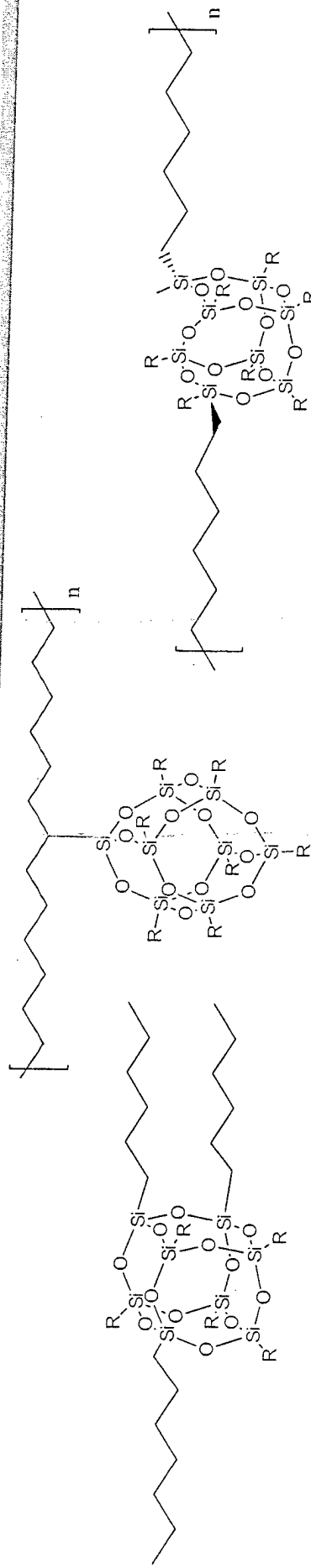
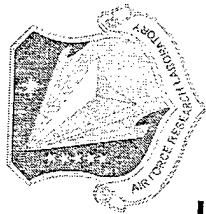
Chain Length vs. Contact Angle



Number of Fluorocarbon Atoms



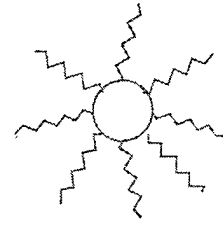
# POSS Polymer Incorporation



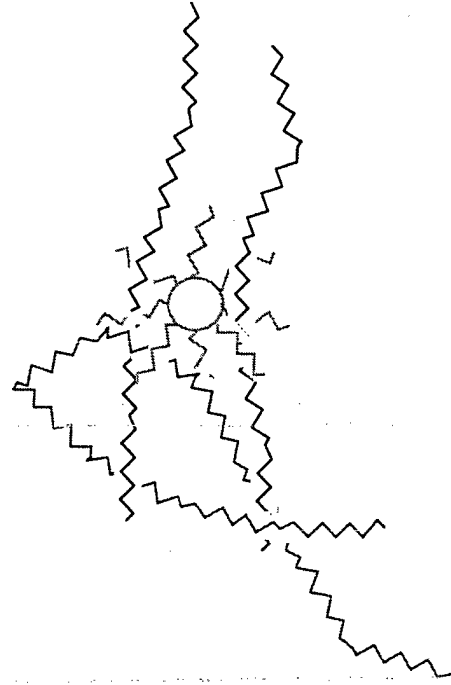
Cross-linker

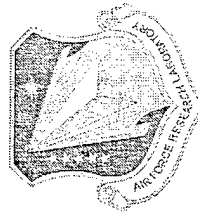
POSS Pendant

Bead Copolymer

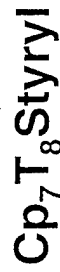


POSS Blending

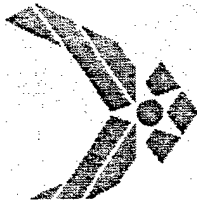




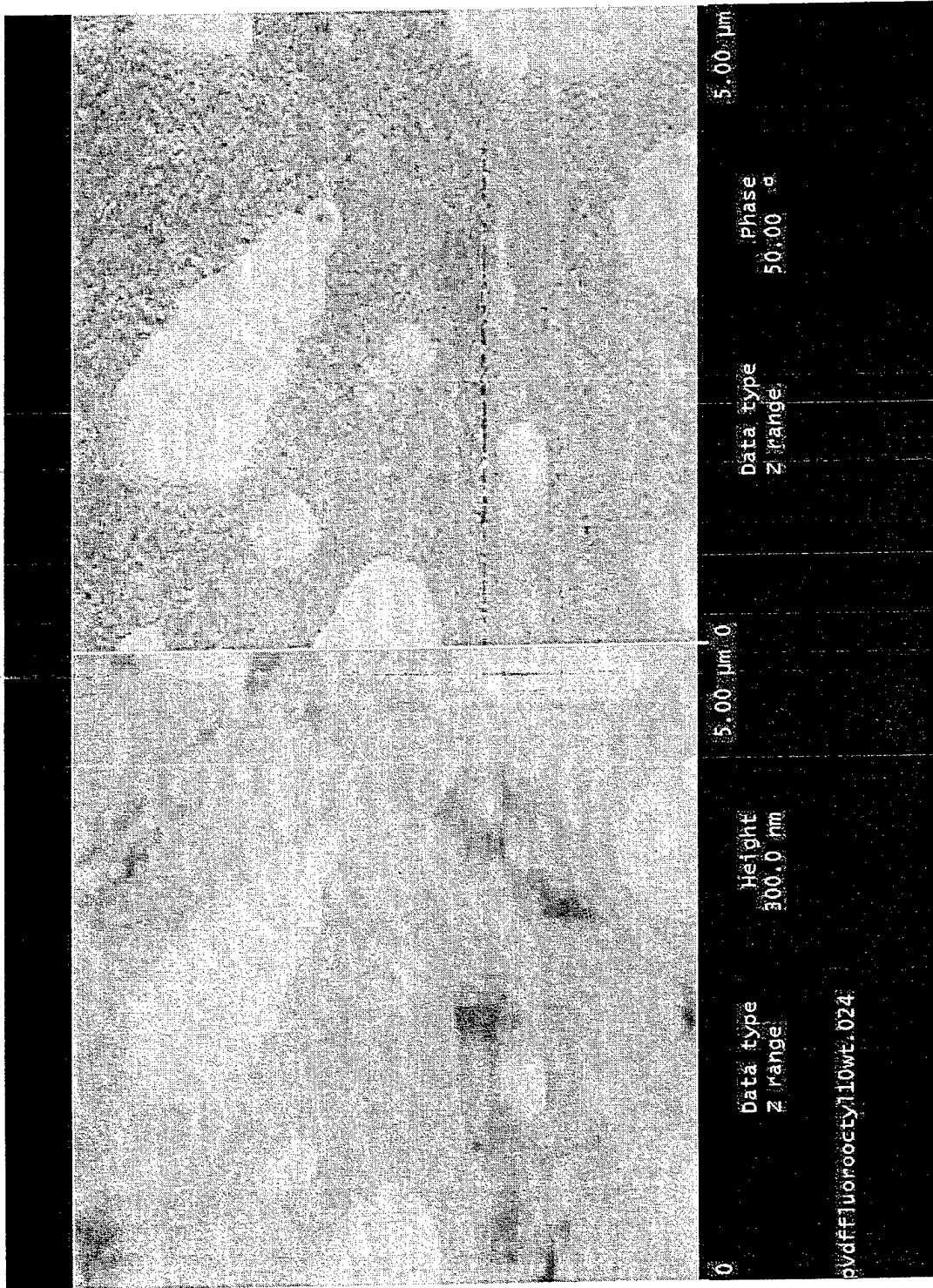
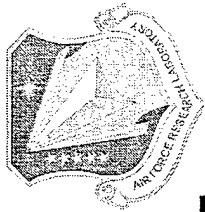
## 50 Wt % POSS Blends in 2 Million MW PS



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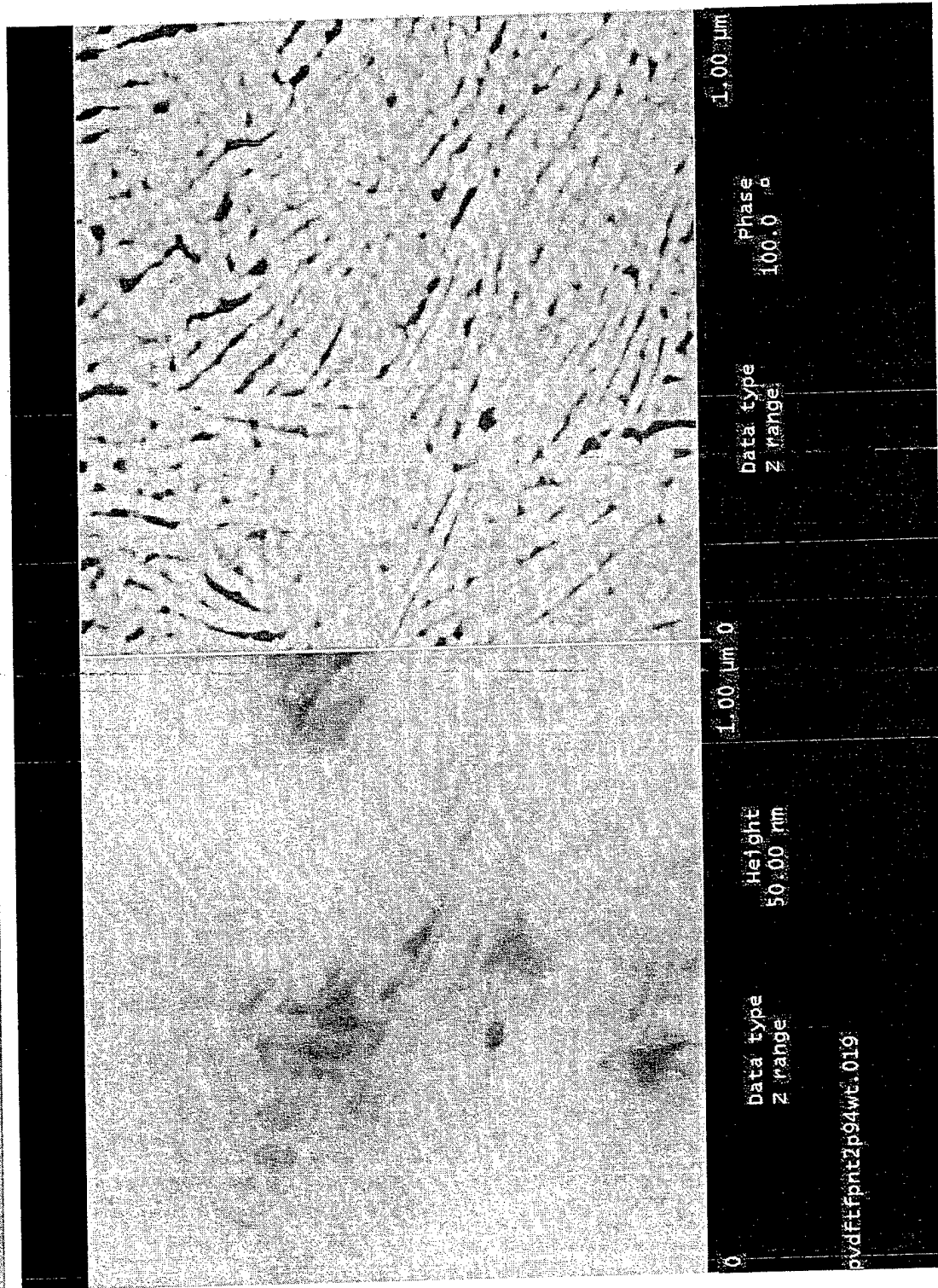
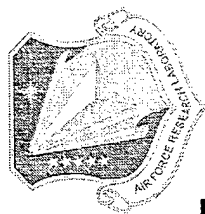
# PVDF/Fluorooctyl<sub>8</sub>T<sub>8</sub> POSS



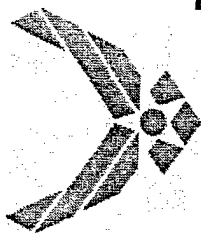
DISTRIBUTION A. Approved for public release; distribution unlimited.



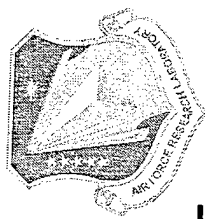
# PVDF/Fluoropropyl<sub>n</sub>T<sub>n</sub> POSS



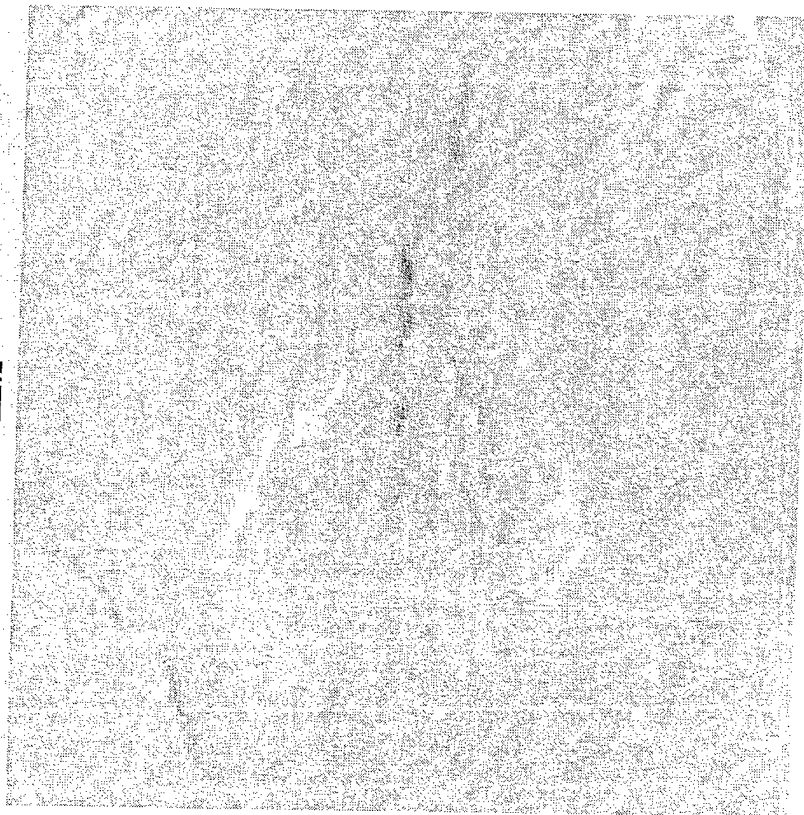
DISTRIBUTION A. Approved for public release; distribution unlimited.



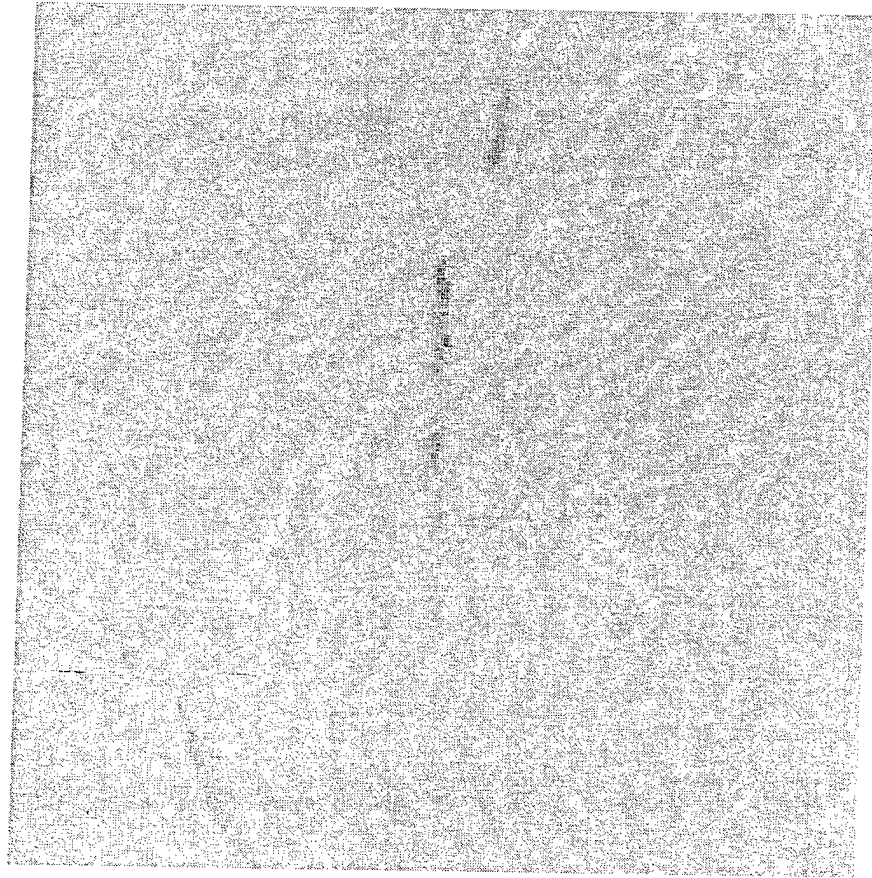
# PVDF/Fluoropropyl<sub>n</sub>T<sub>n</sub> POSS



SEM



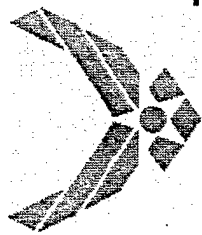
**SEM Image**



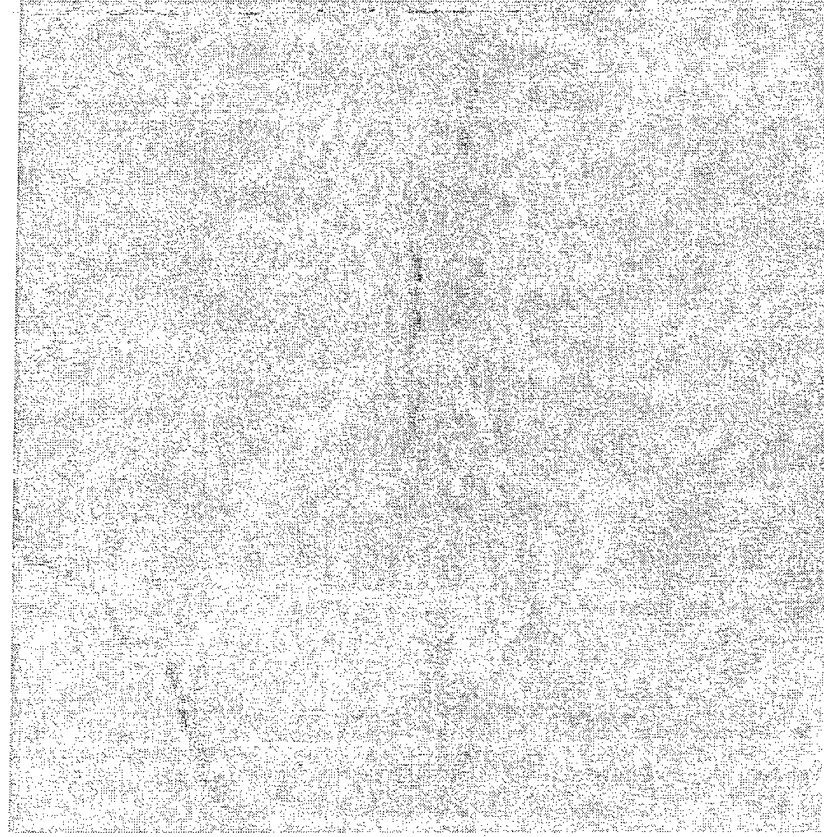
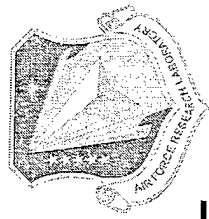
**Carbon Map**

SEM Image taken on cross-section of 1/4 inch thick sample bar.

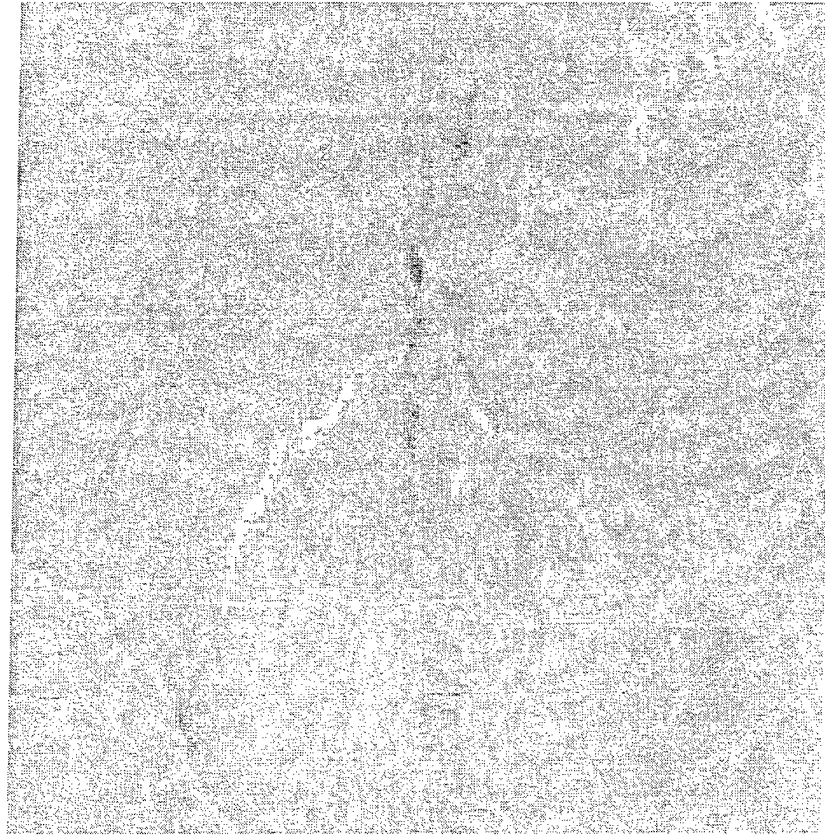
DISTRIBUTION A. Approved for public release; distribution unlimited.



# PVDF/Fluoropropyl<sub>n</sub>T<sub>n</sub> POSS



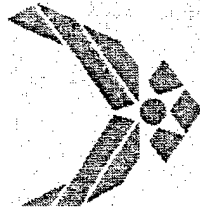
**Fluorine Map**



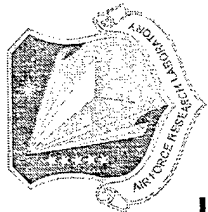
**Silicon Map**

Silicon map shows reasonable dispersion of POSS in polymer.

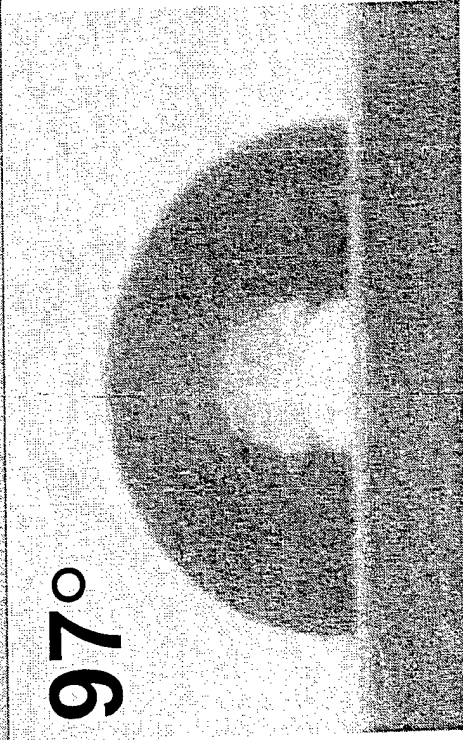
DISTRIBUTION A. Approved for public release; distribution unlimited.



# Fluorinated Ethylene/Propylene

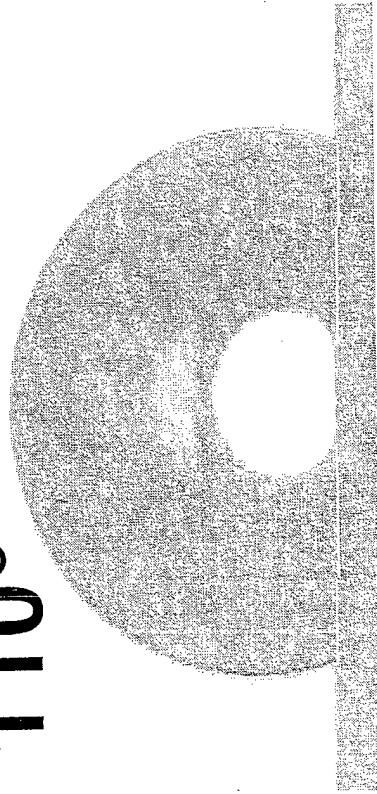


97°



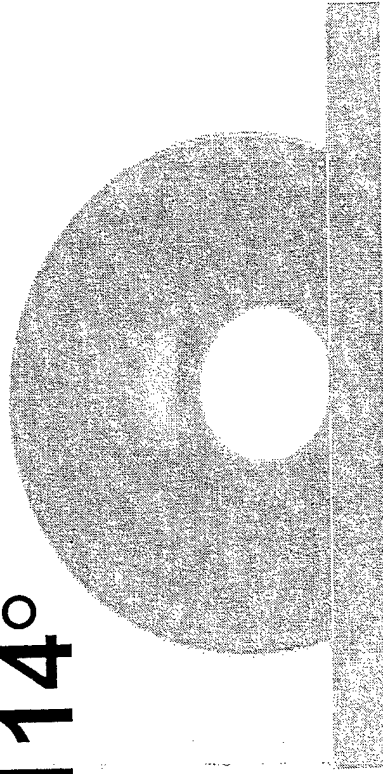
FEP

110°



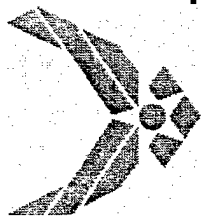
15% FO<sub>8</sub>T<sub>8</sub>

114°

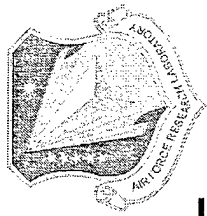


15% FD<sub>8</sub>T<sub>8</sub>

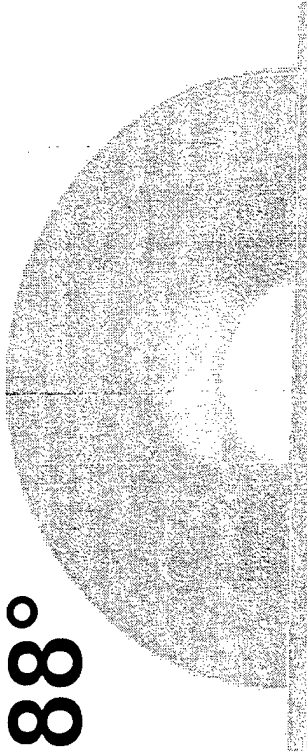
DISTRIBUTION A. Approved for public release; distribution unlimited.



# Poly(chlorotrifluoroethylene)

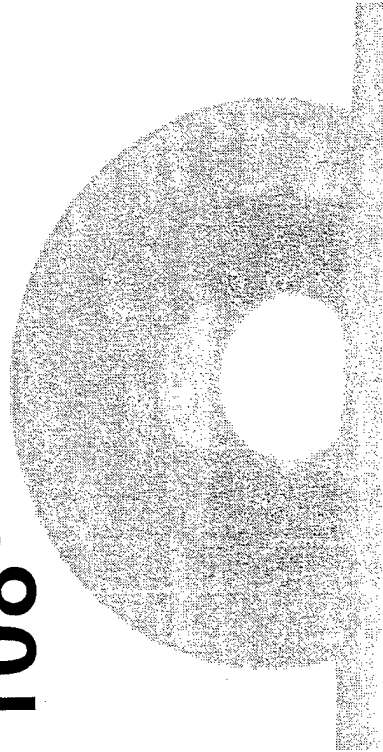


88°



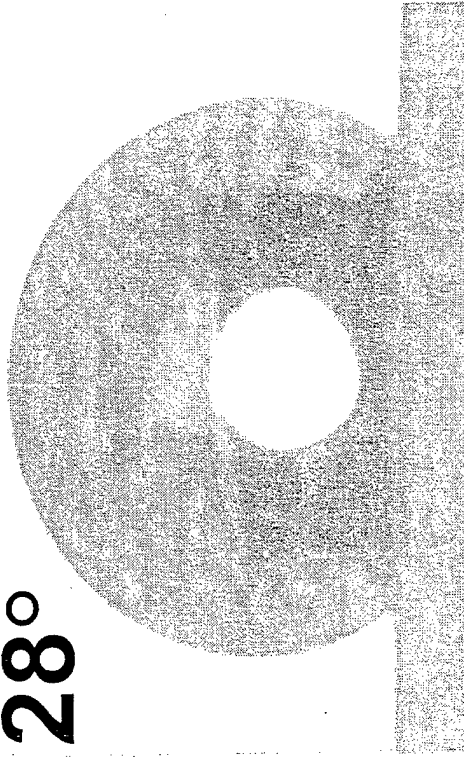
PCTFE

108°



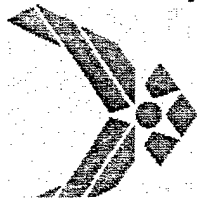
10% FO<sub>8</sub>T<sub>8</sub>

128°

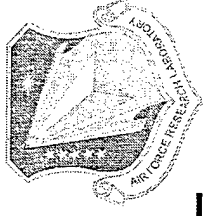


10% FD<sub>8</sub>T<sub>8</sub>

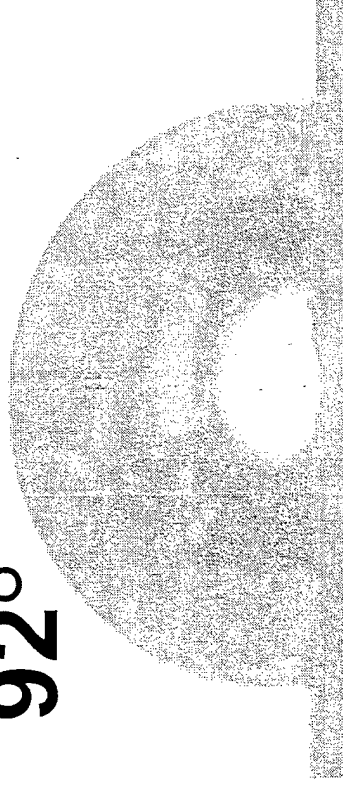
DISTRIBUTION A. Approved for public release; distribution unlimited.



# Amorphous FEP



92°



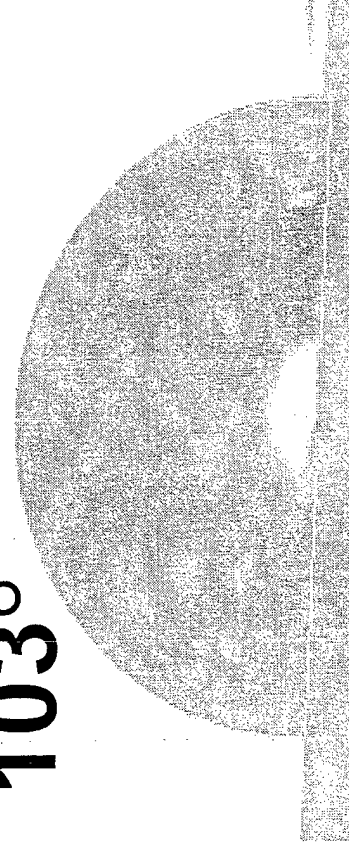
AFEP

100°



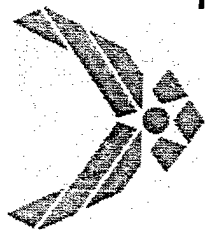
AFEP with 10% FO<sub>8</sub>T<sub>8</sub>

103°

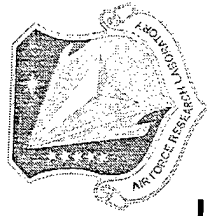


AFEP with 10% FD<sub>8</sub>T<sub>8</sub>

DISTRIBUTION A. Approved for public release; distribution unlimited.



# Water Contact Angle



| Polymer   | No POSS | FO <sub>8</sub> T <sub>8</sub> | FD <sub>8</sub> T <sub>8</sub> |
|-----------|---------|--------------------------------|--------------------------------|
| PCTFE     | 88°     | 108°                           | 128°                           |
| FEP       | 97°     | 110°                           | 114°                           |
| Amor. FEP | 92°     | 100°                           | 103°                           |

Fluoropropyl POSS (FP<sub>n</sub>T<sub>n</sub>)

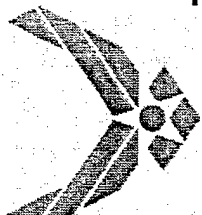
Fluorooctyl POSS (FO<sub>8</sub>T<sub>8</sub>)

Fluorodecyl POSS (FD<sub>8</sub>T<sub>8</sub>)

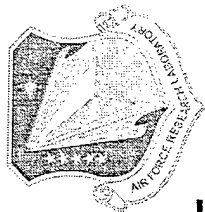
101°

115°

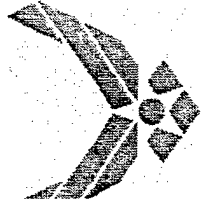
154°



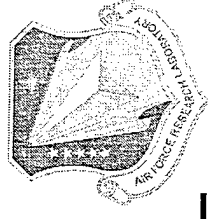
# Summary



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# Acknowledgements



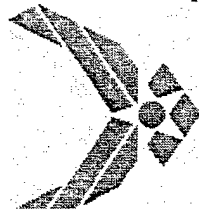
Assistance from others at AFRL:

Crystal Structures  
SEM Images  
SEM Images  
AFM Images

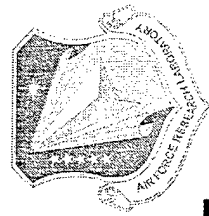
Ashwani Vij  
Marietta Fernandez  
Erik Weber  
Brian Moore

Financial Support:  
Air Force Office of Scientific Research  
Air Force Research Laboratory, Propulsion Directorate

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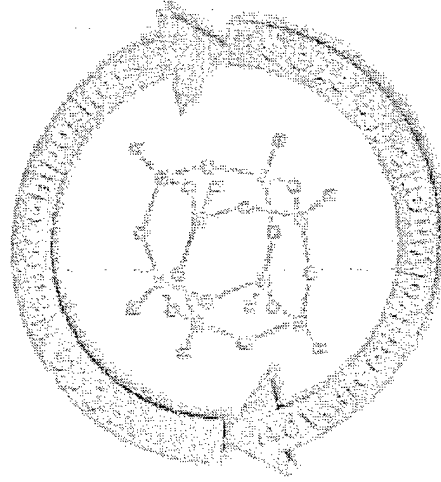


# Acknowledgements



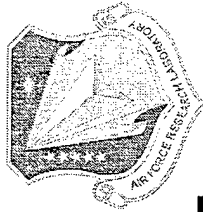
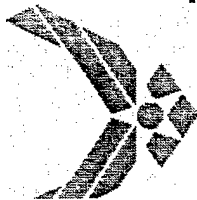
The Polymer Working Group at Edwards Air Force Base is:

Maj Connie Schlaefer  
Mr. Pat Ruth  
Dr. Sandra Tomczak  
Mr. Brian Moore  
Dr. Brent Viers  
Dr. Darrell Marchant  
Lt Will Cooper  
Mr. Scott Barker



Dr. Shawn Phillips  
Lt Amy Palacek  
Dr. Rusty Blanski  
Dr. Joe Mabry  
Mrs. Sherly Largo  
Dr. Tim Haddad  
Lt Laura Moody

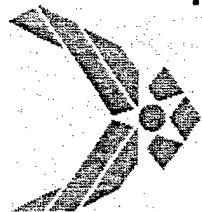
Financial Support:  
Air Force Office of Scientific Research  
Air Force Research Laboratory, Propulsion Directorate



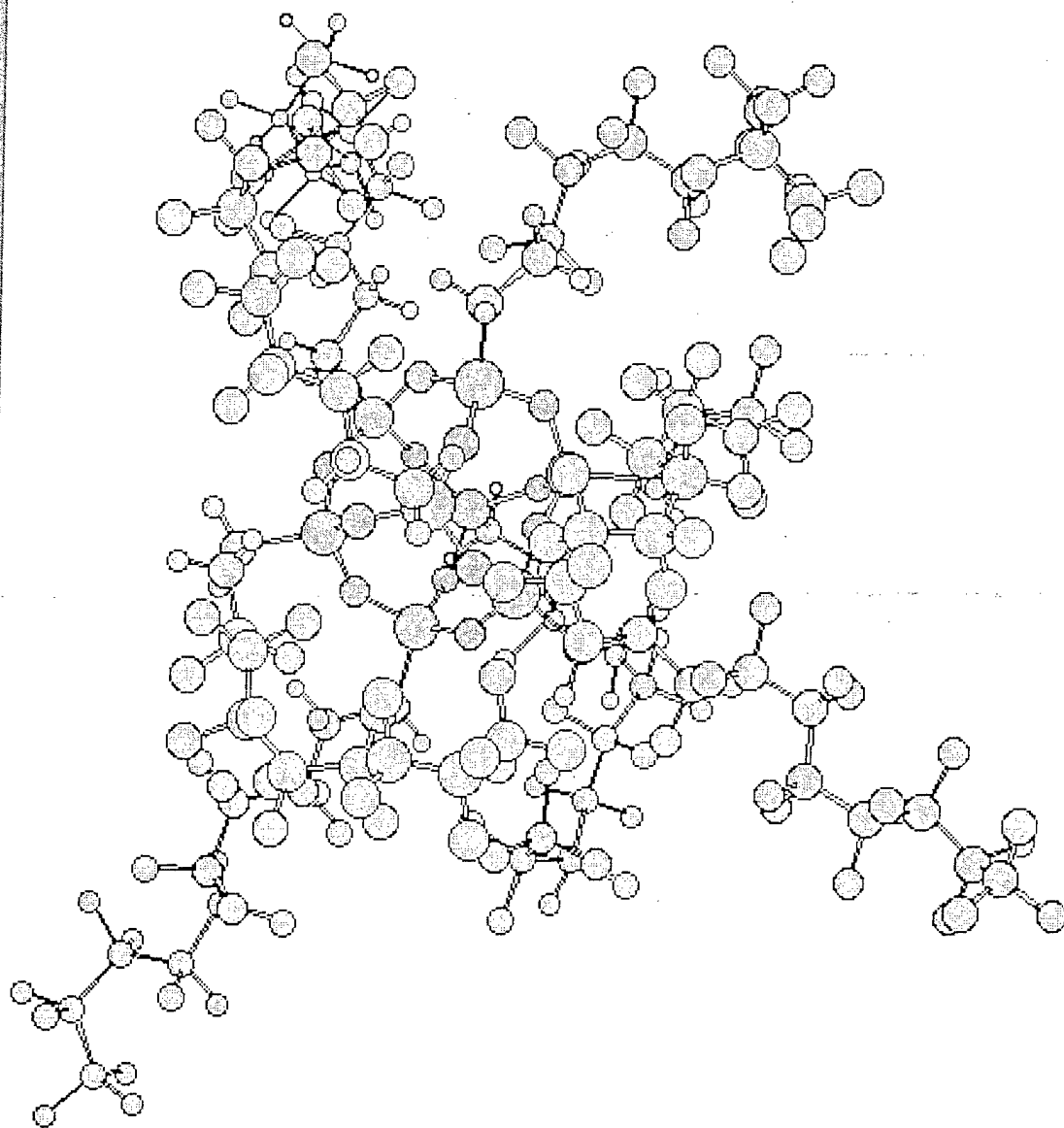
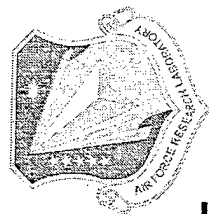
# Backup Slides

PAS-03-061

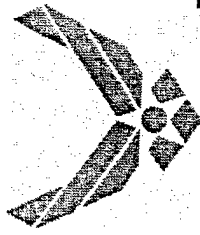
DISTRIBUTION A. Approved for public release; distribution unlimited.



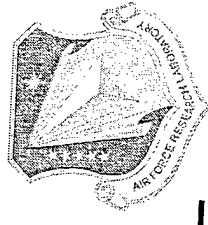
# Gas Phase Model of Fluorodecyl<sub>8</sub>T<sub>8</sub>



DISTRIBUTION A. Approved for public release; distribution unlimited.

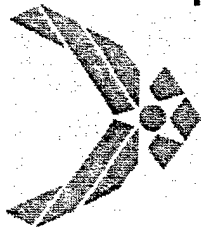


# Density

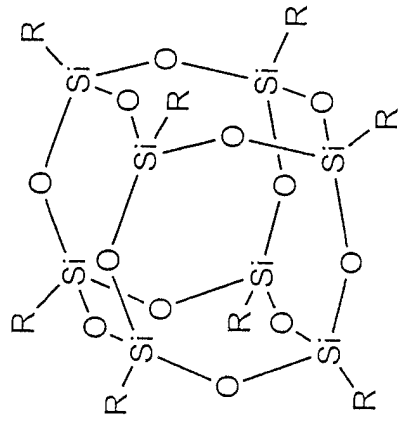
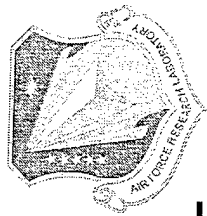


| <u>Compound</u>              | <u>Density (g/mL)</u> |
|------------------------------|-----------------------|
| • PVDF                       | 1.75-1.78             |
| • PCTFE                      | 2.08-2.19             |
| • FEP                        | 2.12-2.17             |
| • Fluoropropyl POSS          | 1.59                  |
| • Fluorohexyl POSS (crystal) | 1.86 (1.98)           |
| • Fluorooctyl POSS (crystal) | 1.88 (2.05)           |
| • Fluorodecyl POSS (crystal) | 1.95 (2.06)           |

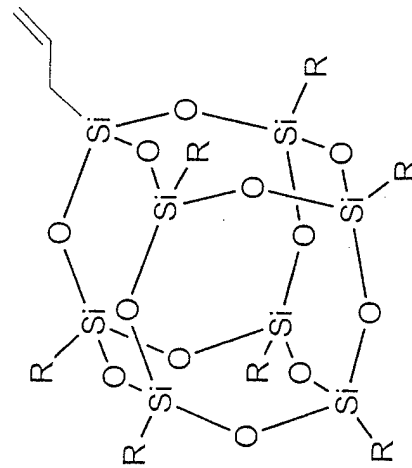
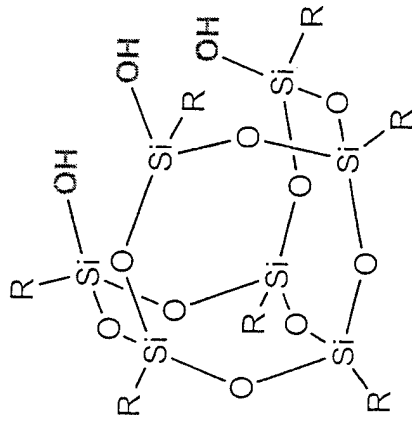
DISTRIBUTION A. Approved for public release; distribution unlimited.



# Fluorinated POSS Trisilanol



$\xrightarrow[\text{reflux}]{\text{Et}_4\text{NOH}}$

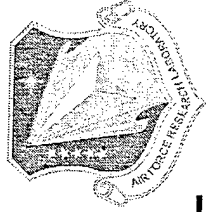
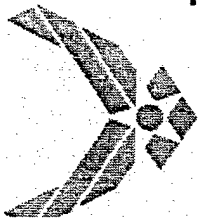


$\xrightarrow{\text{Et}_3\text{N}}$

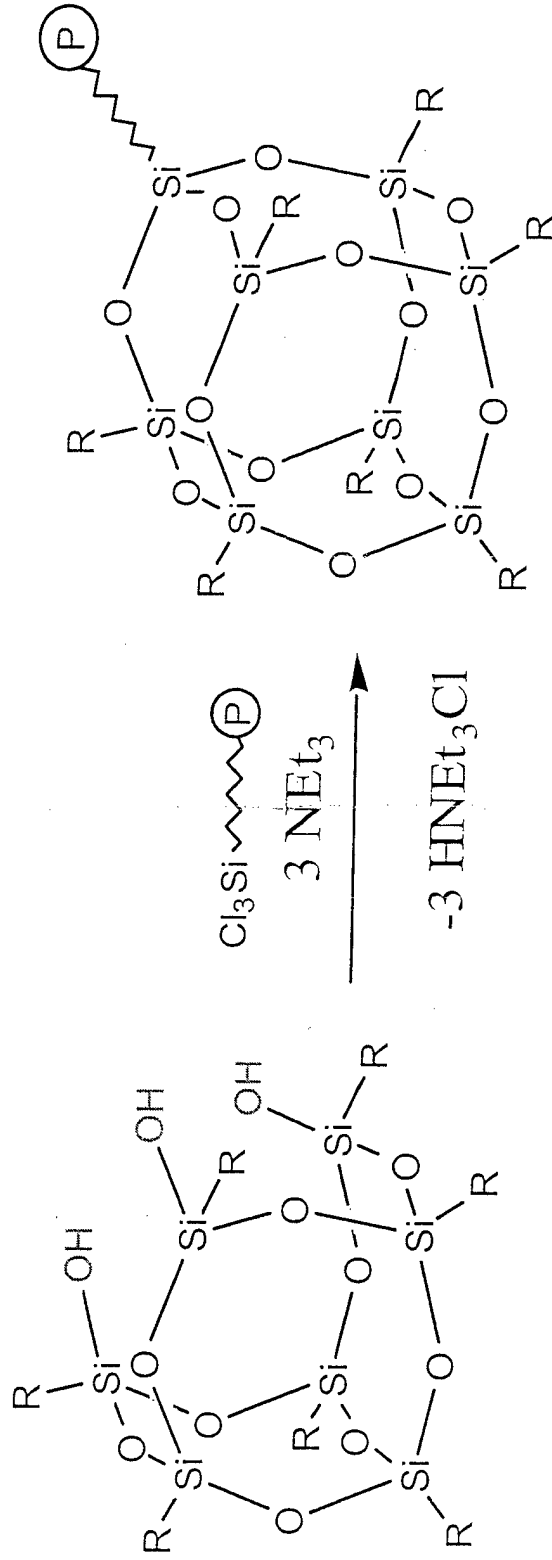


(or other chlorosilanes)

DISTRIBUTION A. Approved for public release; distribution unlimited.



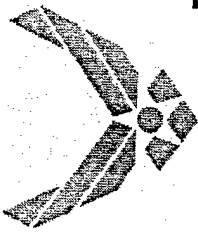
# POSS Macromers for Nanocomposites



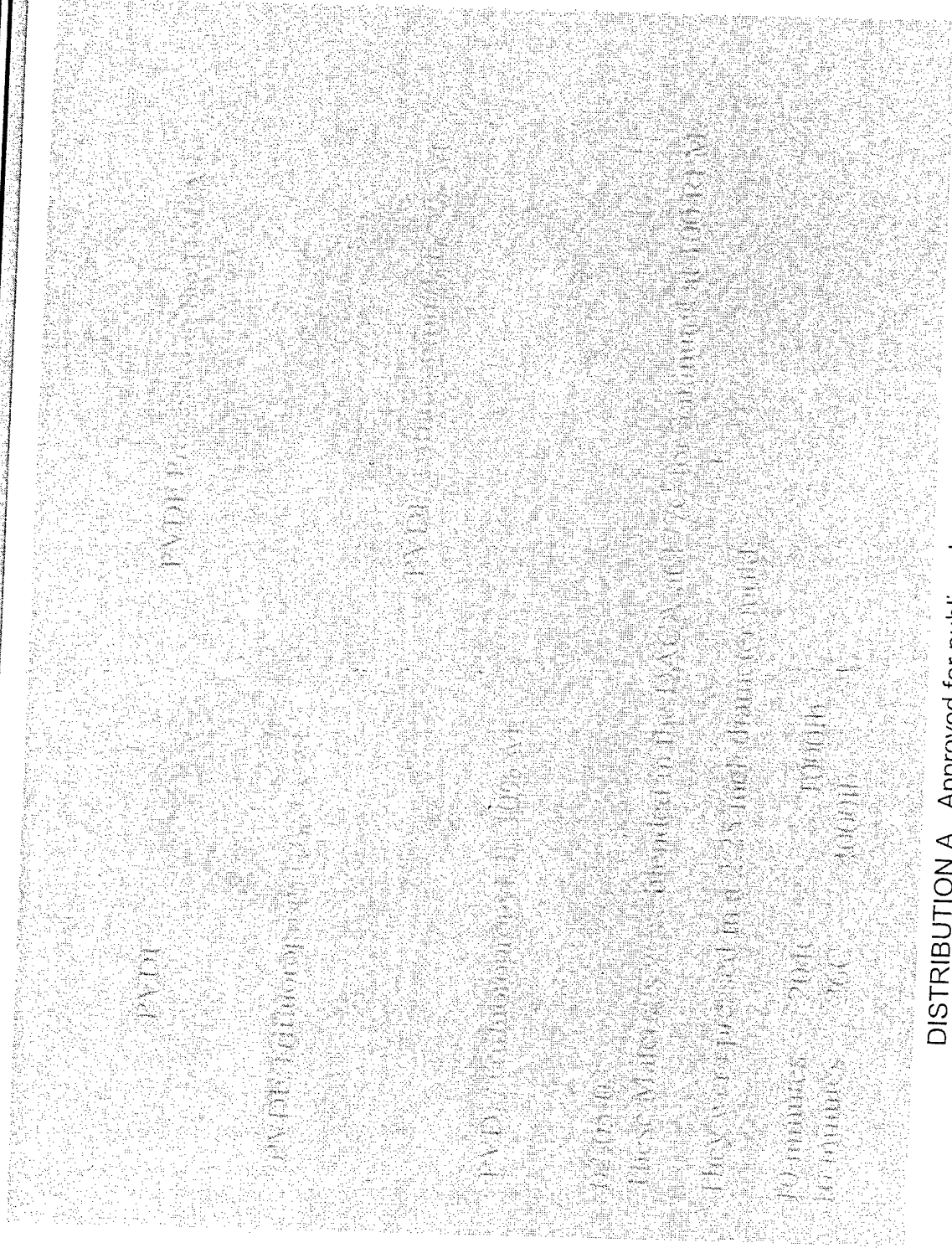
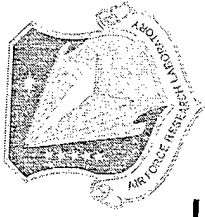
POSS-based macromers are available through either **Gelest** or **Aldrich**  
POSS technology is commercialized by **Hybrid Plastics** in Fountain Valley CA

PAS-03-061

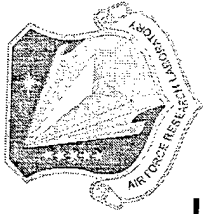
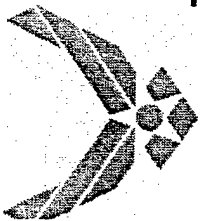
DISTRIBUTION A. Approved for public release; distribution unlimited.



# PVDF Fluoropropyl<sub>n</sub>T<sub>n</sub> Blends



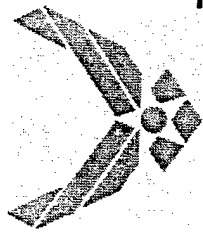
DISTRIBUTION A. Approved for public release; distribution unlimited.



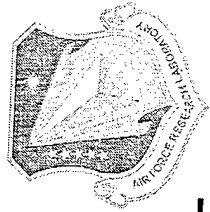
# POSS Siloxanes

PAS-03-061

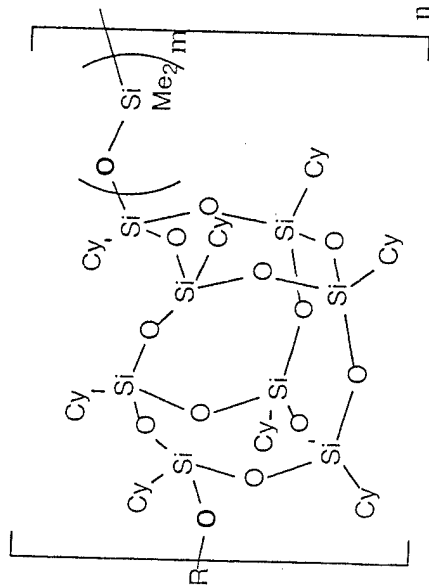
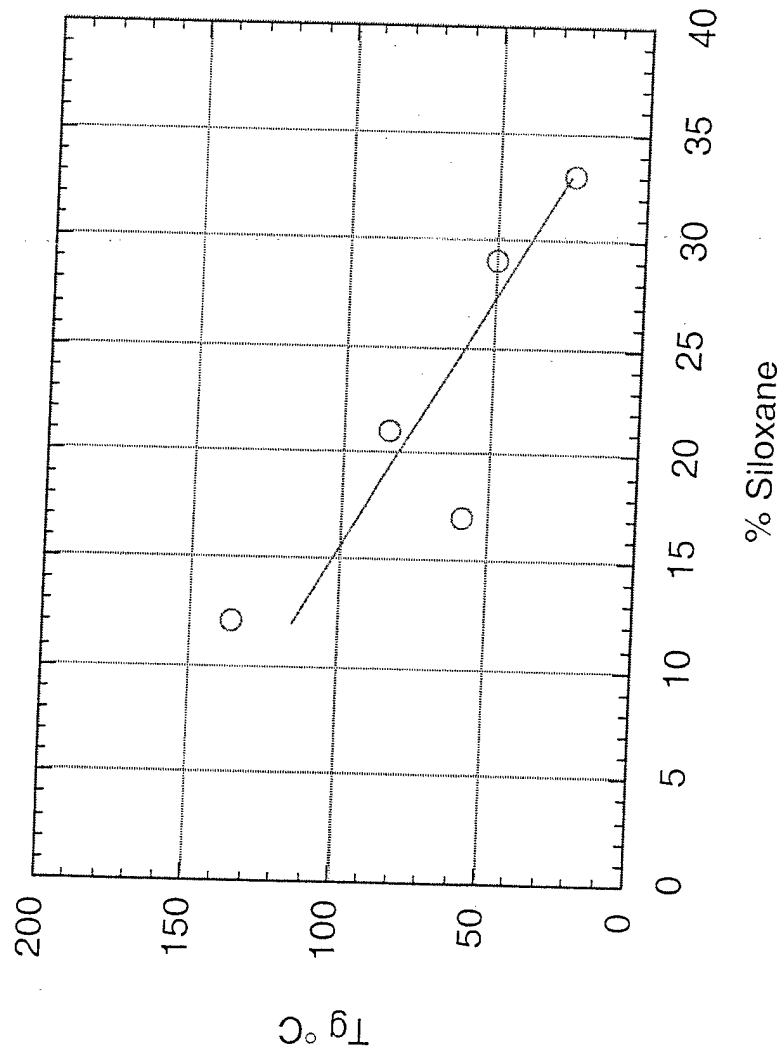
DISTRIBUTION A. Approved for public release; distribution unlimited.



# Tg's For Bead Siloxane Copolymers



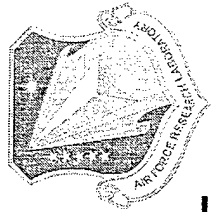
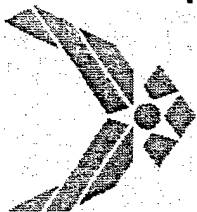
Glass Transition vs % Siloxane



POSS Bead acts as a hard segment

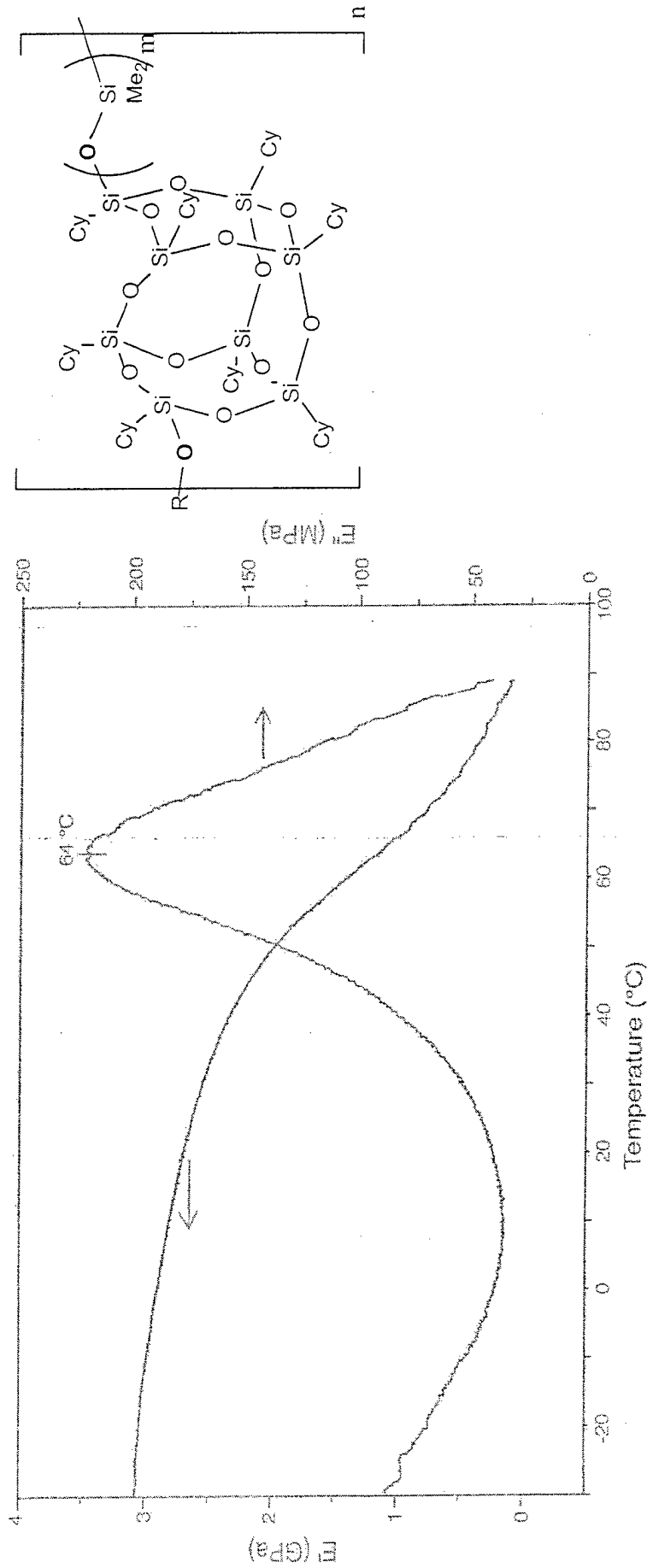
PAS-03-061

DISTRIBUTION A. Approved for public release; distribution unlimited.



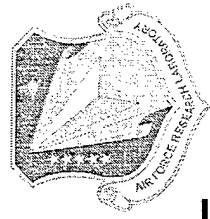
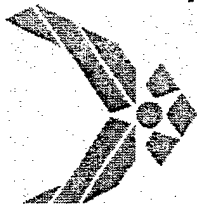
# POSS Siloxanes

- Copolymers with low softening temperatures can be molded into bars.
- Dynamic mechanical analysis reveals a  $T_g$  (64°C).



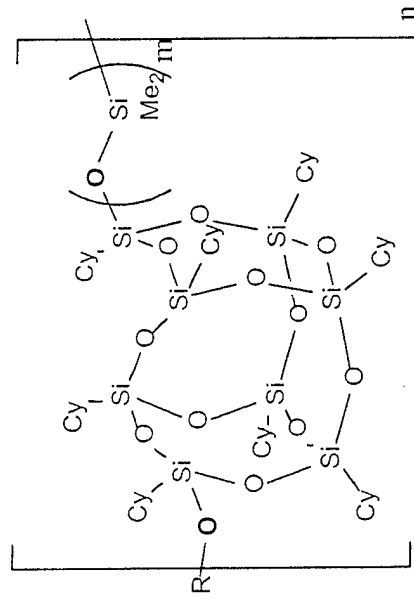
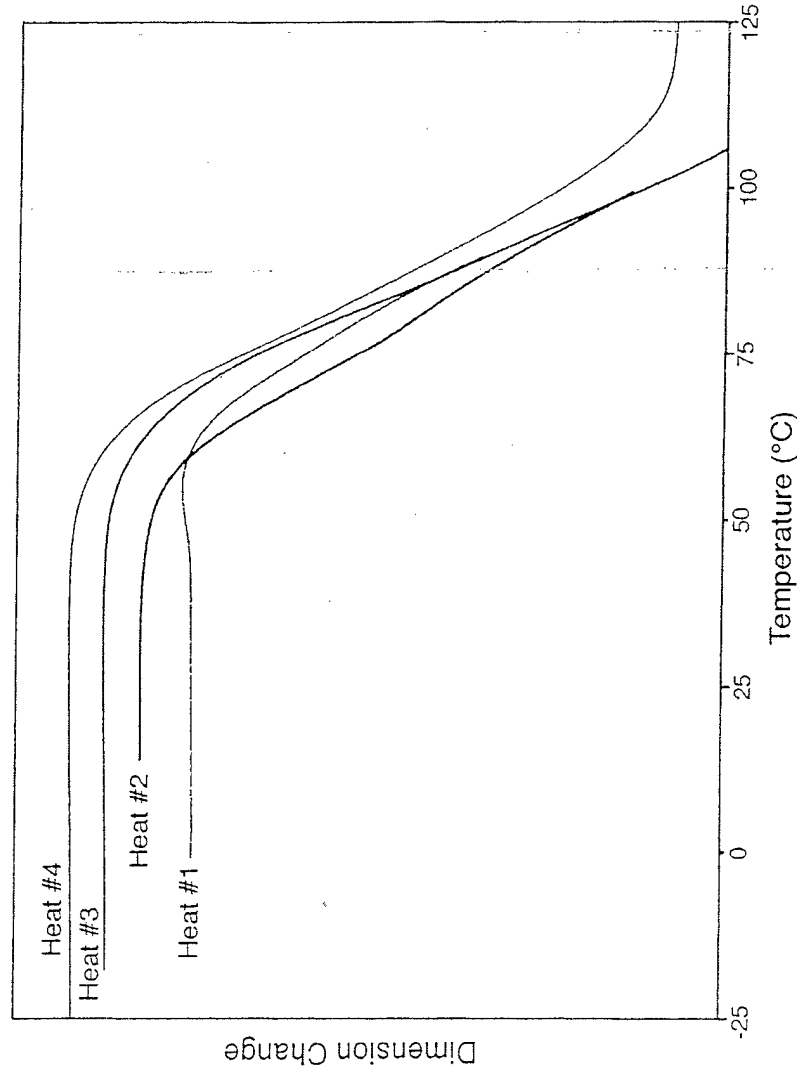
PAS-03-061

DISTRIBUTION A. Approved for public release; distribution unlimited.



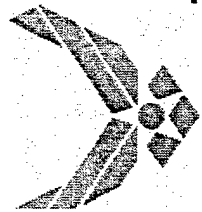
# POSS Siloxanes

The POSS/Siloxane copolymers with four or more Si-O repeat units in the siloxane segment have softening temperatures well below the decomposition temperatures.

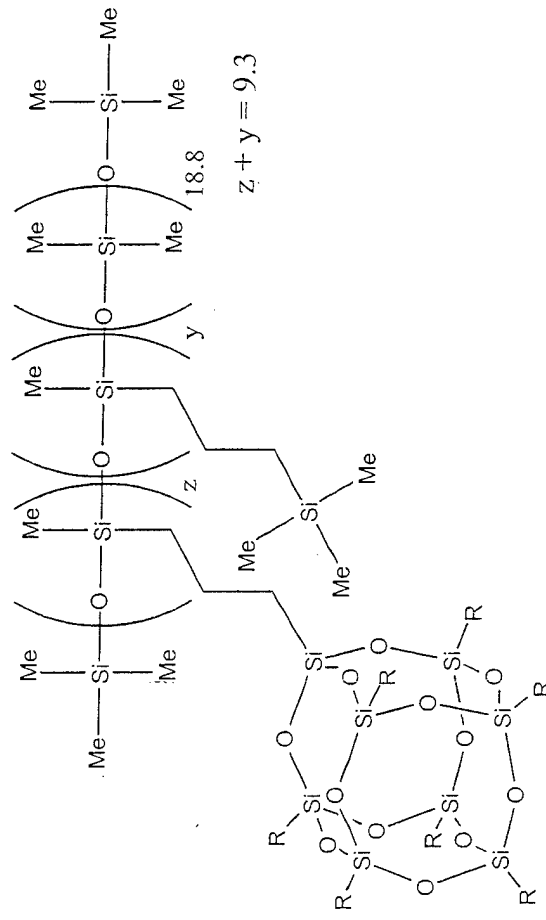
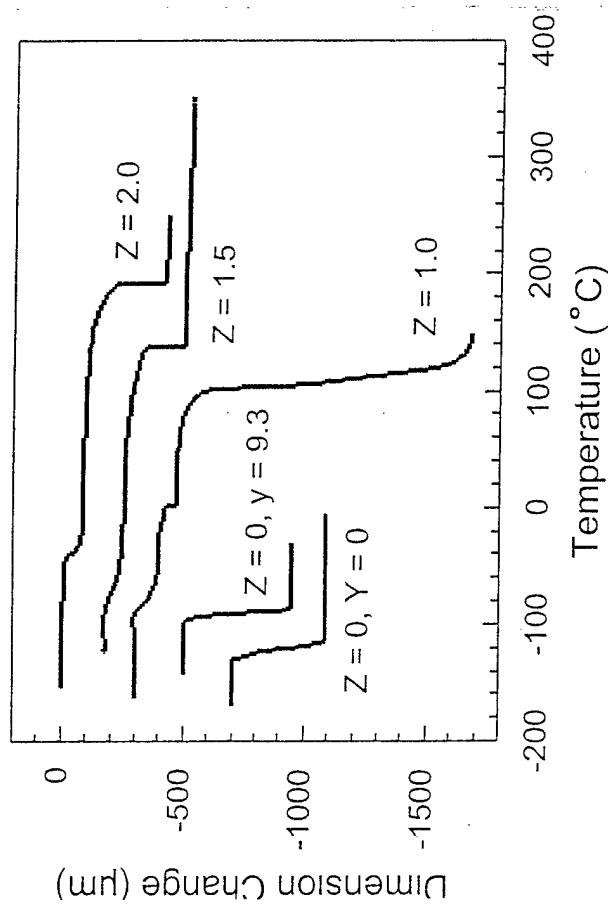
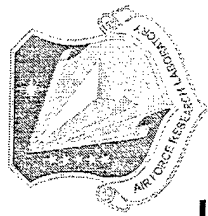


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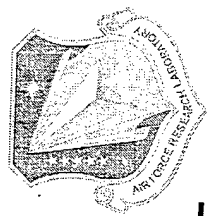


# TMA of Pendent POSS-Siloxanes

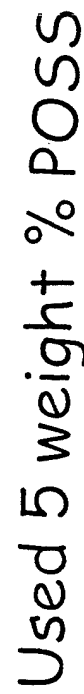


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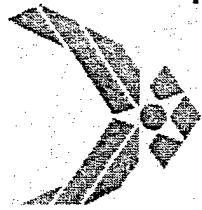
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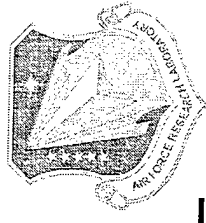
There are about 7 POSS-macromers per PDMS chain



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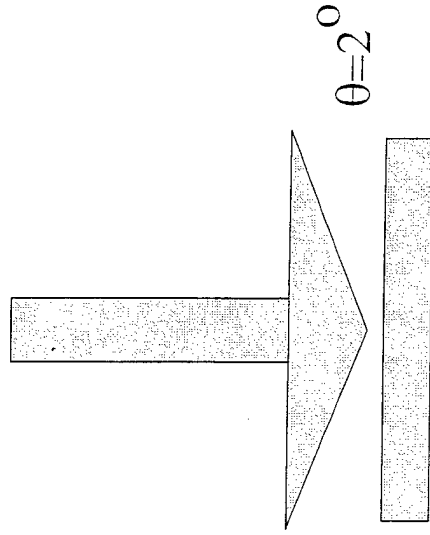
# Experimental Setup for Rheology



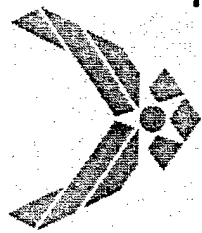
- 25 mm diameter cone-and plate with cone angle of  $2^\circ$  was used.
- The strain amplitude  $\gamma_o$  is 1% and angular frequency  $\omega$  is  $2\pi$  per second.
- The temperature is ramped from -  $60^\circ\text{C}$  to  $70^\circ\text{C}$  with a rate of  $2^\circ\text{C}/\text{min}$ .

$$\gamma(\omega) = \gamma_o \sin(\omega t)$$

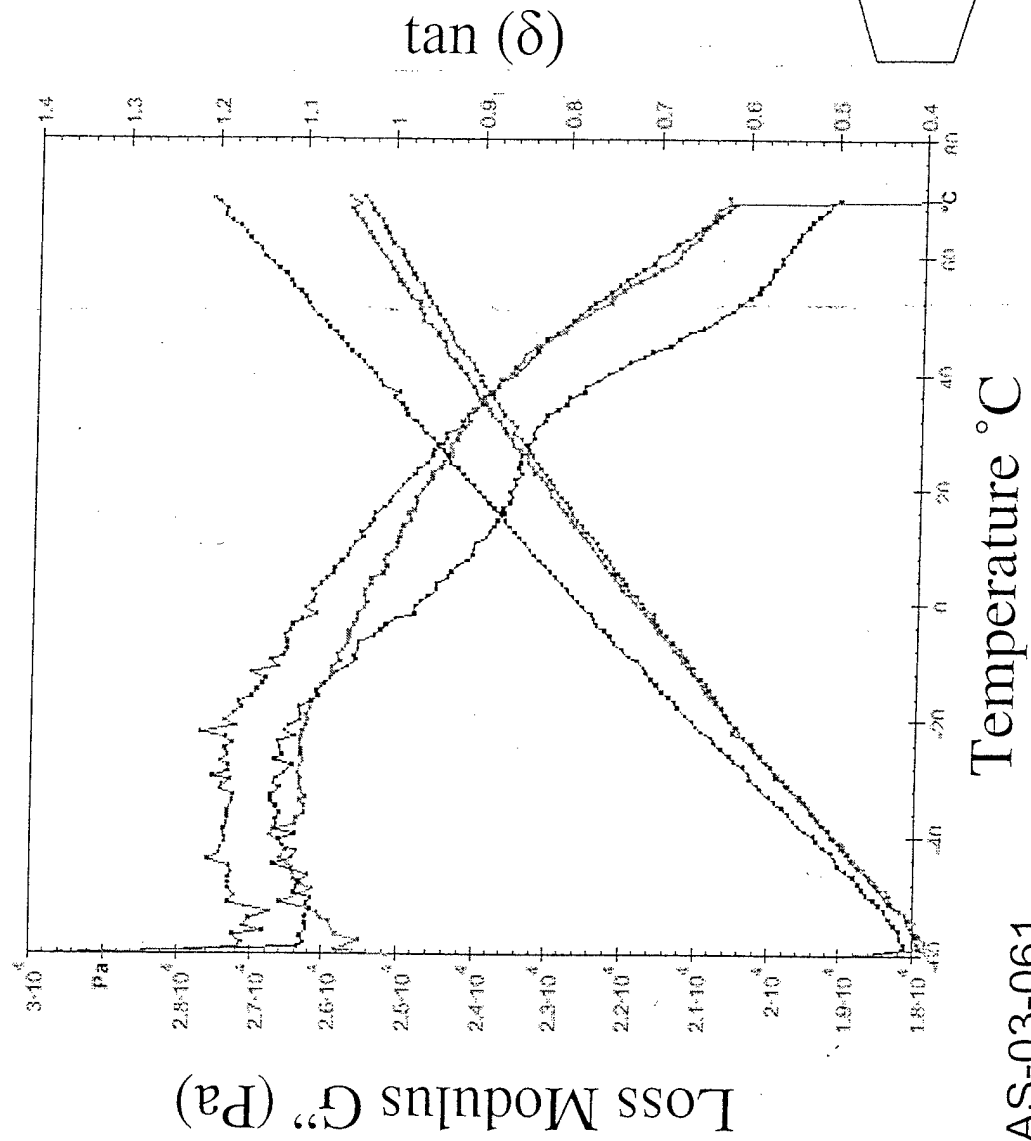
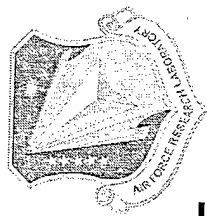
$$\omega = 2\pi (\text{sec}^{-1})$$



The loss modulus  $G''$  and  $\tan\delta = G''/G'$  were obtained as a function of temperature.



# Comparison of Three T8-POSS Macromers

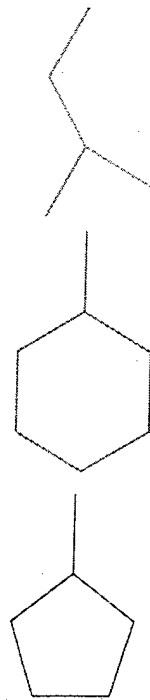
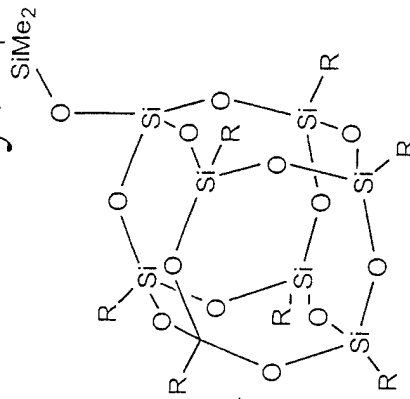


PDMS + 5 wt % POSS

Blue = cyclopentyl

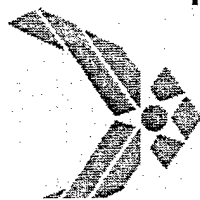
Red = cyclohexyl

Purple = isobutyl

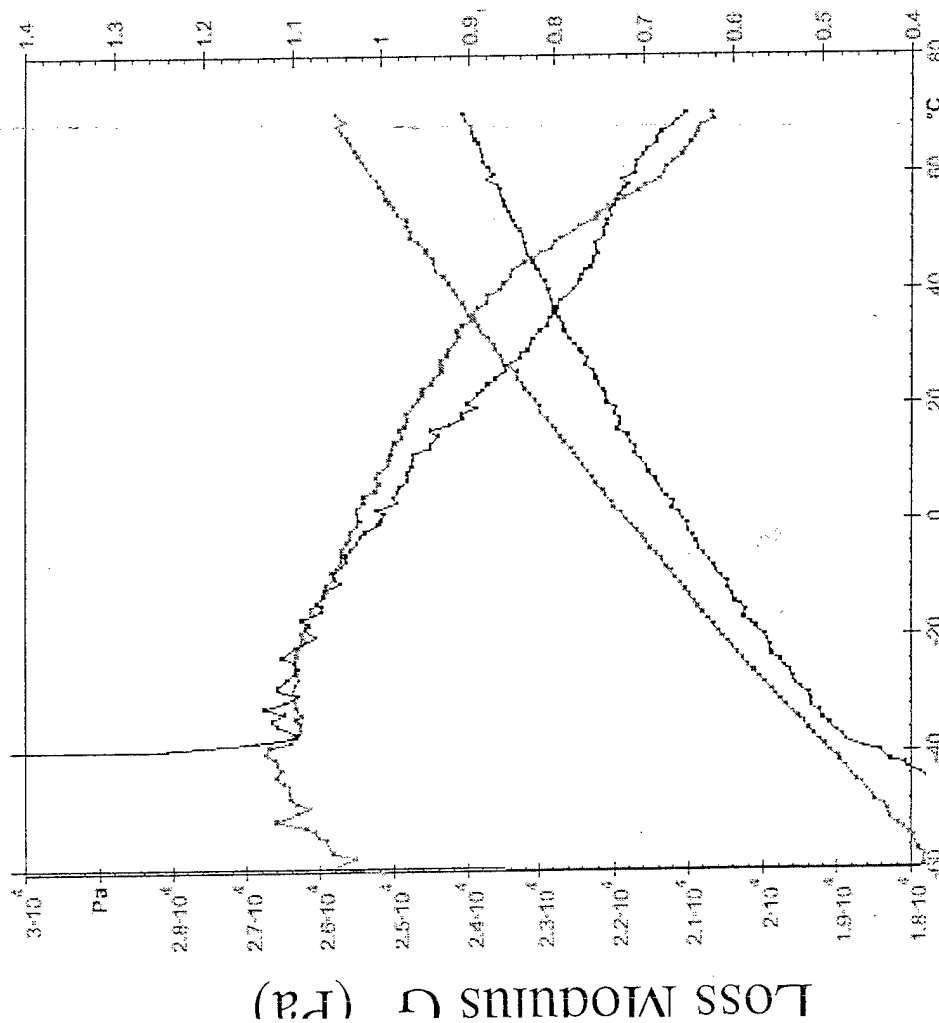
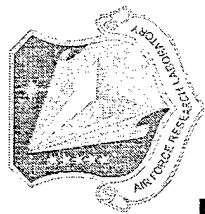


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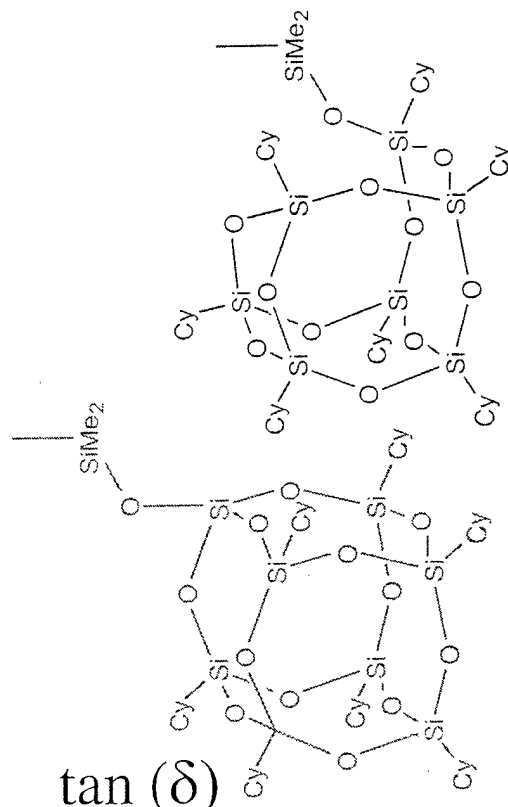


# Comparison of Two POSS Polyhedra



PDMS + 5 wt %  
CyclohexylPOSS  
Red = T8-POSS  
Blue = T7-POSS

$\tan(\delta)$

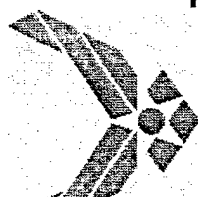


Temperature  $^{\circ}\text{C}$

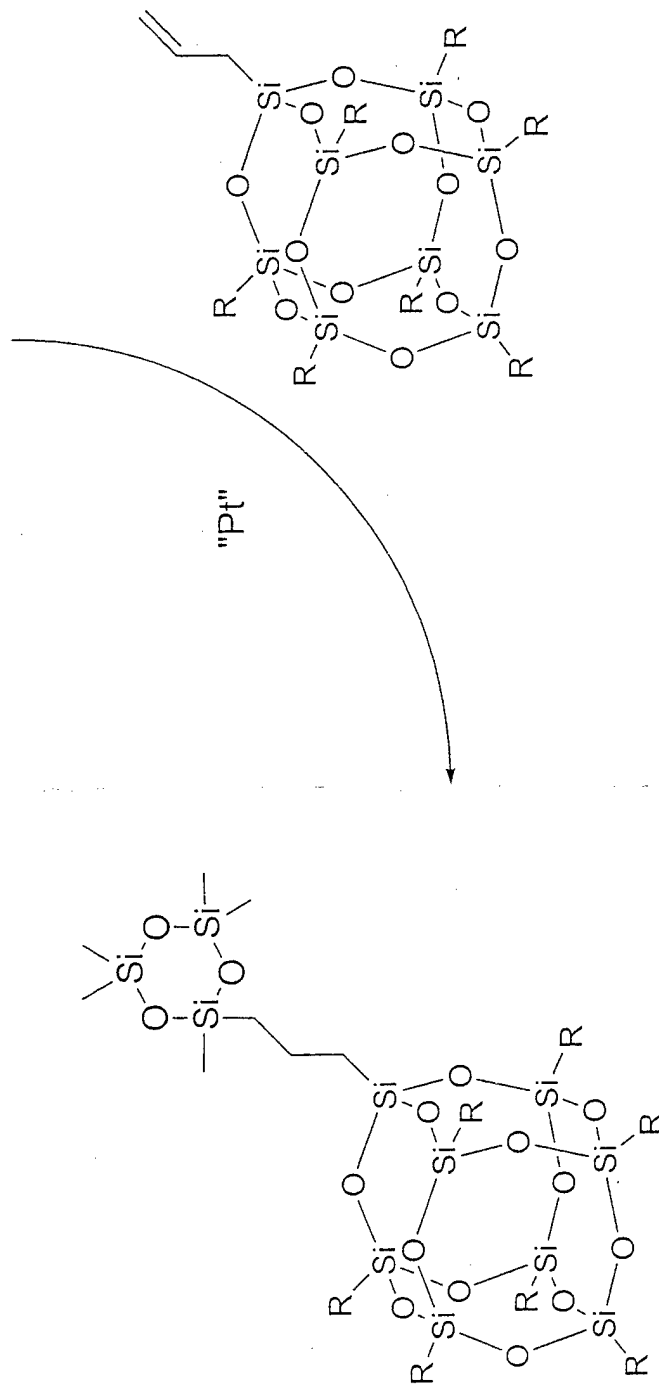
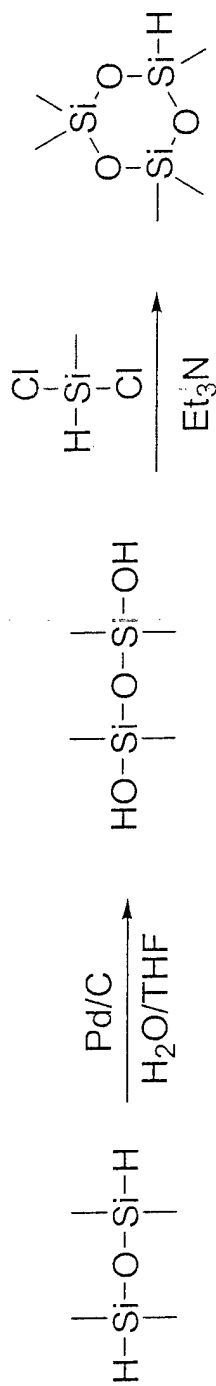
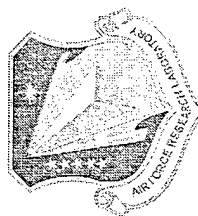
Continue this collaboration with Andre Lee

PAS-03-061

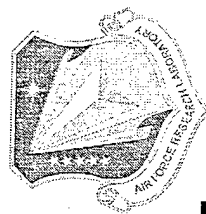
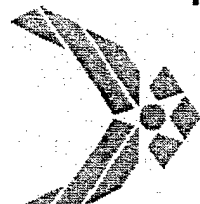
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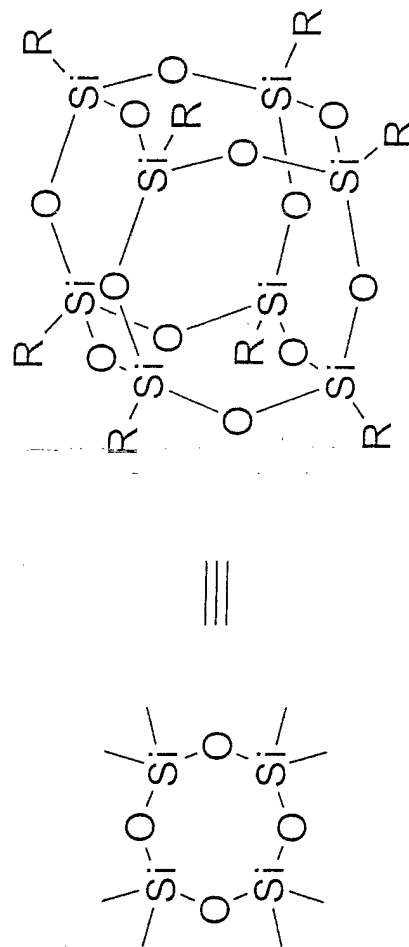
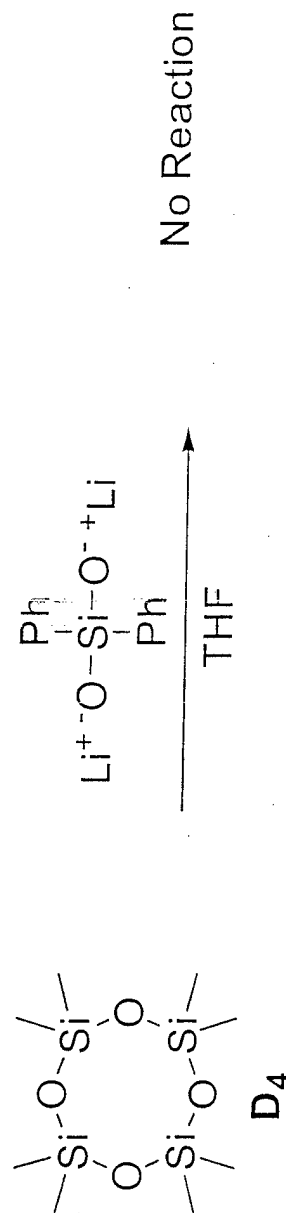
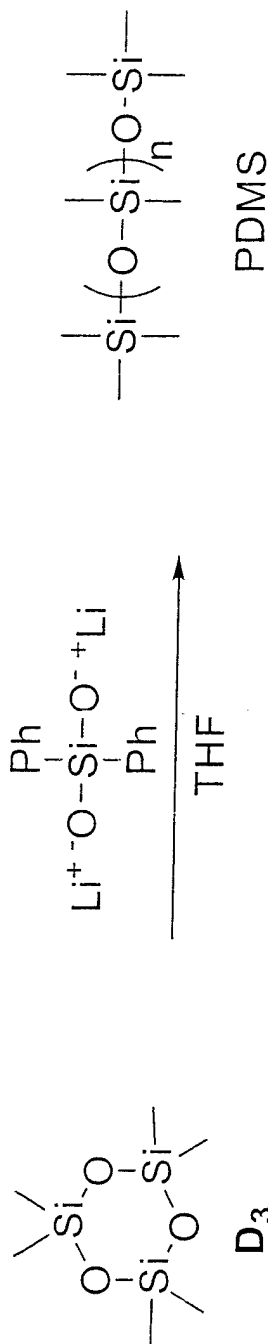
# POSS Cyclotrisiloxane



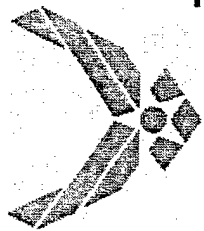
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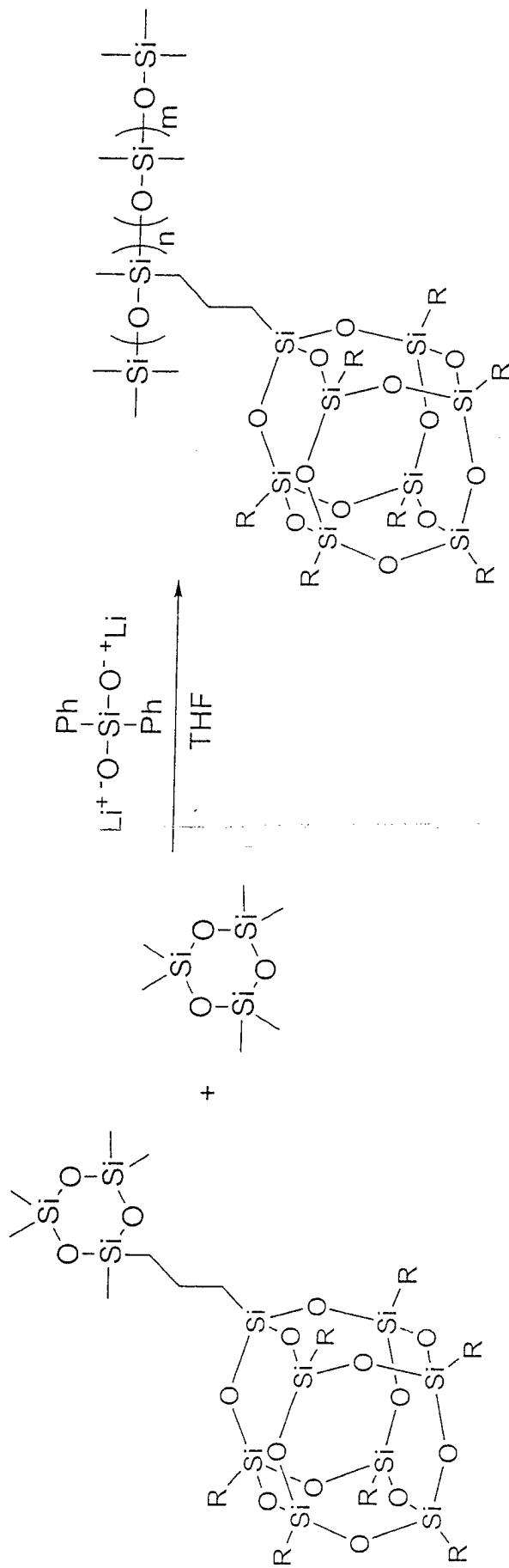
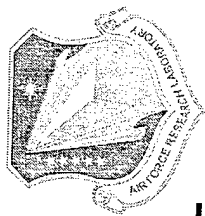
# Reactivity

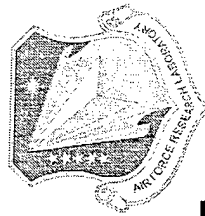
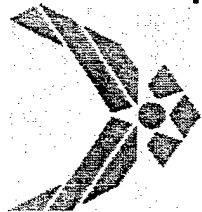


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# POSS Siloxane Copolymers

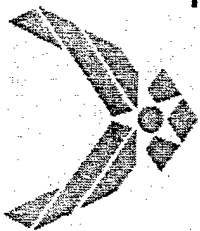




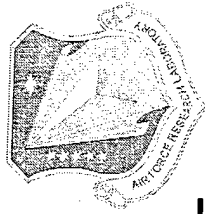
# Space-Survivable Materials

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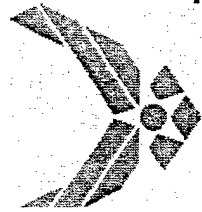


# Space Materials

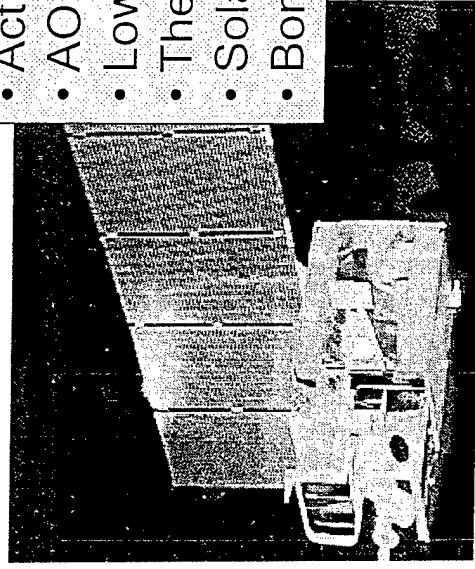
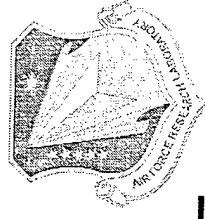


- The International Space Station, the Space Shuttle, and the Hubble Space Telescope are among satellites that operate in Low Earth Orbit (LEO)
- Metallized Teflon FEP is commonly used as outer layer of multi-layer insulation.

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# Space-Survivable Polymers



Satellites & Space Systems

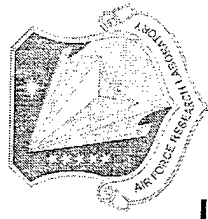
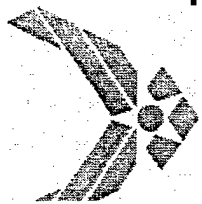
## LEO Environment (Altitudes of 200 to 1500 km)

- Atomic Oxygen (AO):  $\sim 10^8$  atoms/cm<sup>3</sup>
- Actual AO flux on spacecraft  $\sim 10^{15}$  atoms/cm<sup>2</sup>•s
- AO Collision energy  $\sim 5\text{eV}$  (7.8 km/sec)
- Low-energy and high energy charged particles.
- Thermal cycling -50 to 150°C
- Solar VUV and UV radiation ( $\sim 150 - 400$  nm).
- Bond scission and radical formation can lead to embrittlement.

| Bond                             | Dissociation Energy (eV) | $\lambda$ (nm) | Material      |
|----------------------------------|--------------------------|----------------|---------------|
| CF <sub>2</sub> -CF <sub>2</sub> | 4.3                      | 290            | FEP Teflon®   |
| CF <sub>2</sub> -F               | 5.5                      | 230            | FEP Teflon®   |
| Si-O                             | 8.3                      | 150            | Nanocomposite |

## Objectives

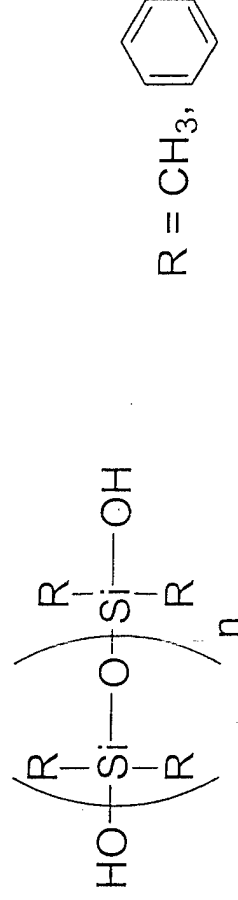
- Increase space-survivability of polymeric materials
- Develop self-passivating layer based on nanocomposite incorporation



# Siloxanes

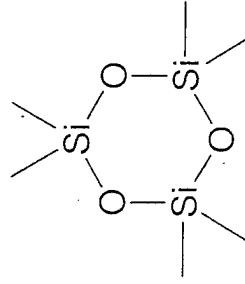
Siloxanes systems exhibit superior resistance to AO

- High Si-O bond strength ~ 8 eV



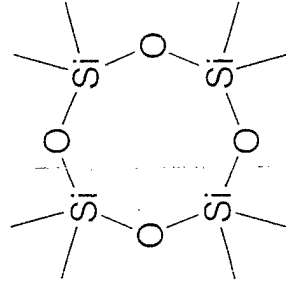
However, pure siloxane systems have disadvantages

- Volatile cyclic species which recondense on optical surfaces



Cyclo(Me<sub>2</sub>SiO)<sub>3</sub>

(D<sub>3</sub>)



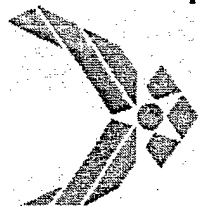
Cyclo(Me<sub>2</sub>SiO)<sub>4</sub>

(D<sub>4</sub>)

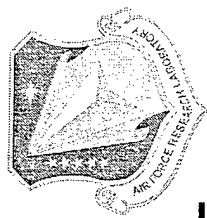
Cyclo(Me<sub>2</sub>SiO)<sub>5</sub> (D<sub>5</sub>)

Cyclo(Me<sub>2</sub>SiO)<sub>6</sub> (D<sub>6</sub>)

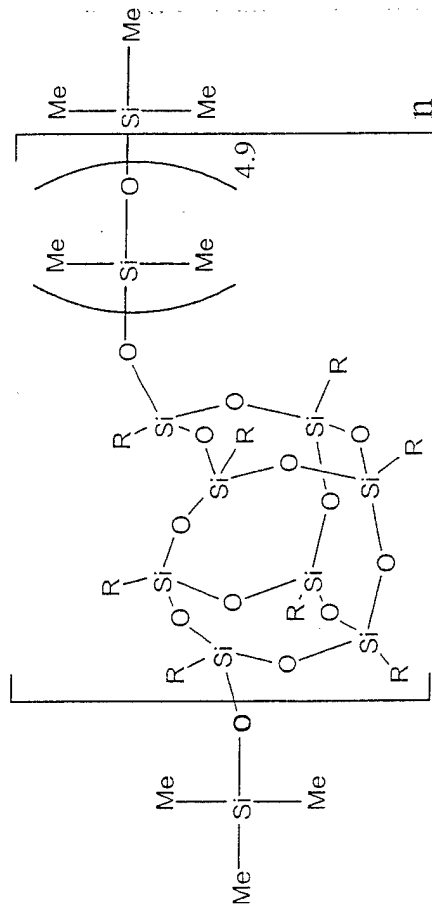
Cyclo(Me<sub>2</sub>SiO)<sub>7</sub> (D<sub>7</sub>)



# POSS-Siloxane



After AO exposure, POSS siloxane had no erosion



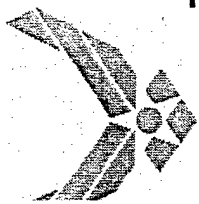
Composition, at %

| Sample Treatment | C    | O    | Si   |
|------------------|------|------|------|
| As entered       | 65.0 | 18.5 | 16.6 |
| 2.0 hr           | 48.4 | 33.8 | 17.8 |
| 24.6 hr          | 22.1 | 49.1 | 28.8 |
| 63.0 hr          | 16.3 | 55.7 | 28.0 |
| 4.8 hr air       | 19.5 | 52.8 | 27.7 |

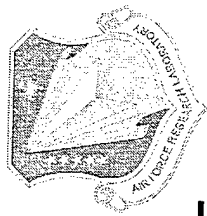
Gonzalez, R. L., Phillips, S. H., Hoflund, G. B., *J. of Spacecraft and Rockets*, Vol 37, No. 4, 2000, pp. 463-467.

XPS survey spectra obtained from a solvent-cleaned, POSS-PDMS film.

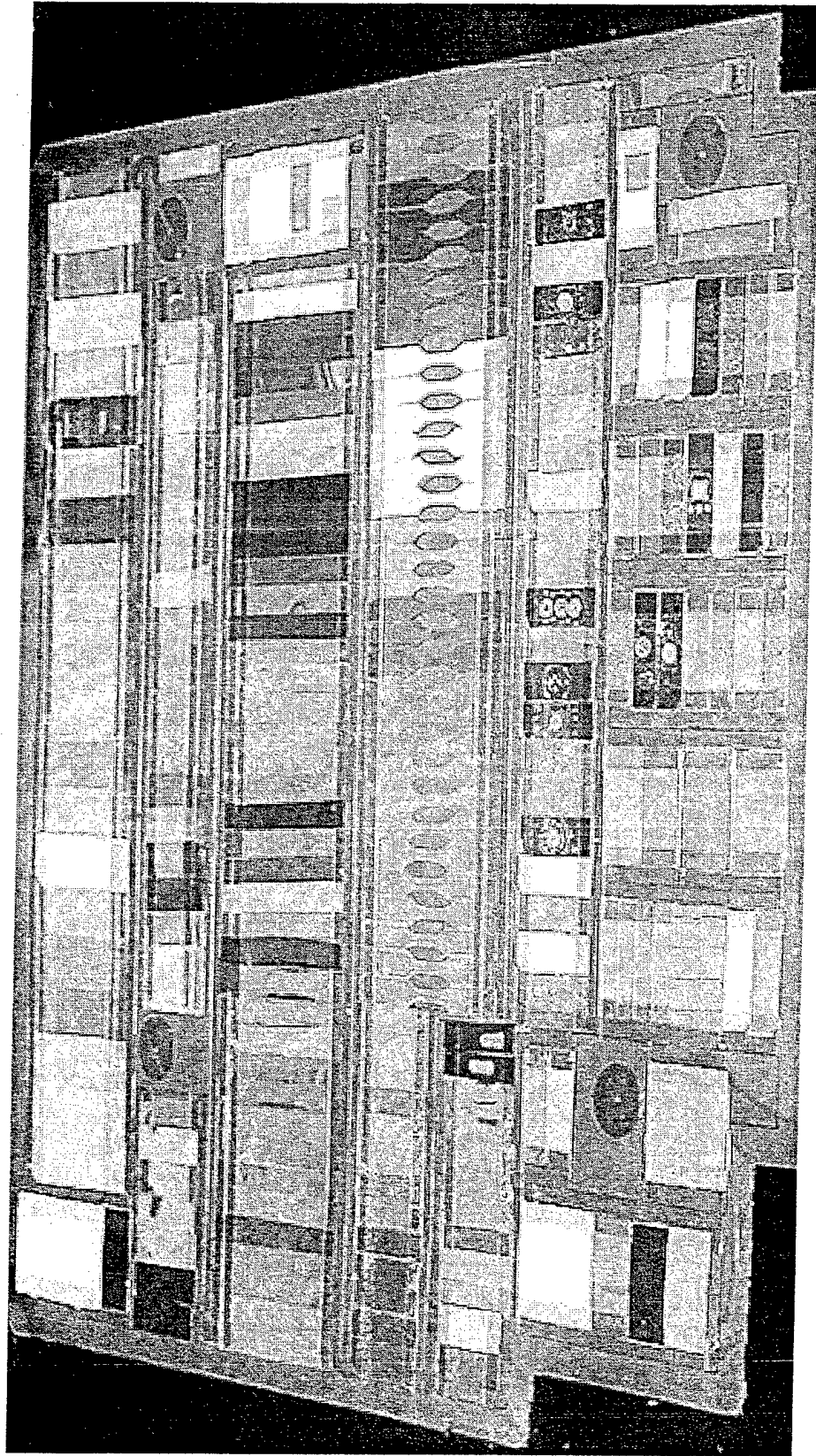
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# Materials International Space Station Experiment (MISSE)



## MISSE 5



**Pictures courtesy of NASA**

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