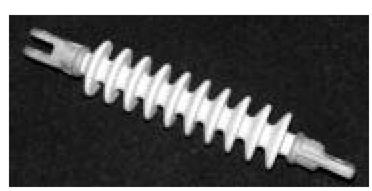
Ceramic vs. Polymer (Non-Ceramic) Insulators

March 2002
Andrew Phillips
EPRI

Polymers History

- Late 1950s: Lightweight NCI considered necessary for 1,000 kV lines
- 1959: GE develops first NCI, but experiences problems with tracking & erosion of epoxy sheds



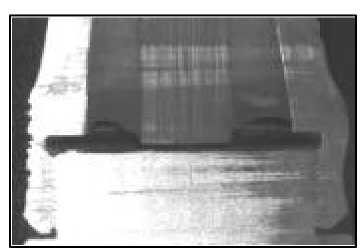
- Early 1960s: Europeans introduce first generation of modern Polymers (fiberglass rod covered with various types of polymer sheds & hardware

Advantage of polymers over ceramics

- 90% weight reduction
- Reduced breakage
- Lower installation costs
- Aesthetically more pleasing
- Improved resistance to vandalism
- Improved handling of shock loads
- Improved power frequency insulation
- Improved contamination performance

Early Problems

- Tracking and erosion Þ flashover and line drops
- Chalking and crazing Þ incr. Contamination, arcing, and flashover
- Bonding failures Þ flashover Þ Failure
- Hardware separation, failures of fiberglass core Þ line drops
- Splitting of sheds, water penetration Þ electrical failure



Result

- Some manufacturers left the business
- Some focused on Transmission Polymers only
- Some focused on Distribution Polymers only
- Some developed second- and third-generation Polymers

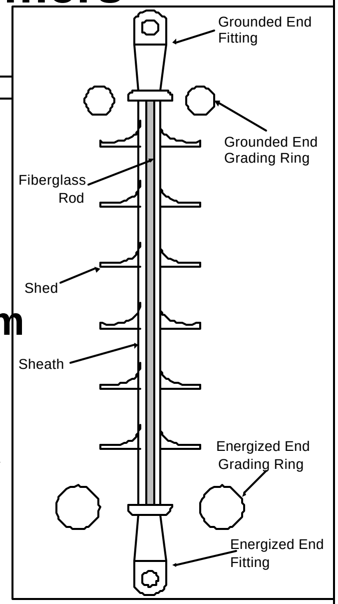
Polymers Applied As:

- Suspension insulators: carry tension loads in I-string, Vee-string, and dead-end applications
- Post insulators: Carry tension, bending, or compression loads
- Phase-to-phase insulators: Loaded in tension, torsion, bending, or compression to couple two phases together to control conductor spacing during galloping

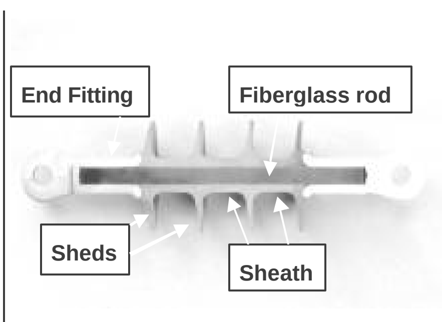
Elements of Modern Polymers

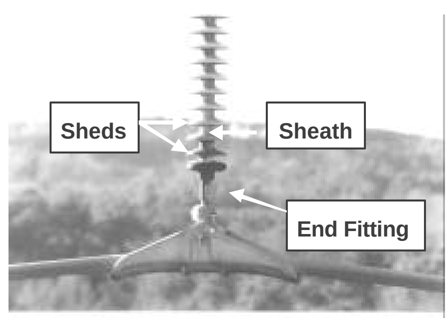
- Energized metallic end fitting
- Energized end grading ring*
- Fiberglass reinforced plastic rod (FRP)
- Polymeric weathershed system (weathersheds and sheath)
- Grounded end grading ring*
- Grounded metallic end fitting*

***Not all applications**



Basic Make-up





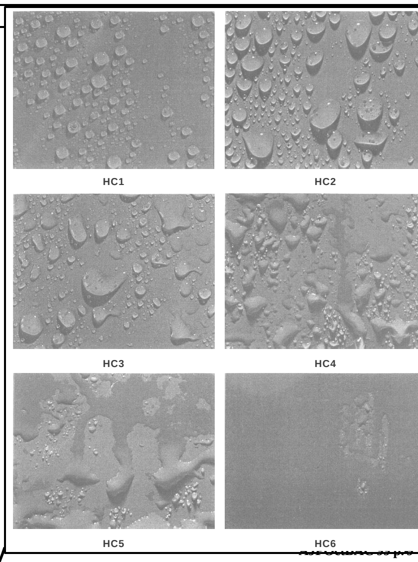
Cross-section through a Distribution Class NCI

(Basic makeup is identical to a transmission class NCI)

Photograph of Suspension NCI showing main components

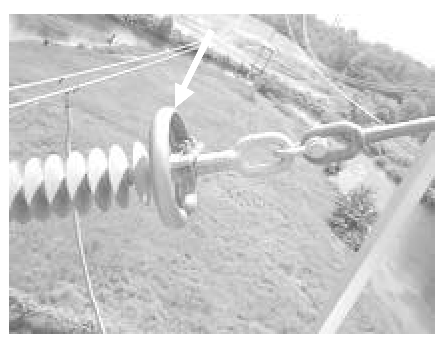
Hydrophobicity (Appendix D TR 111- 566)

- **Surface wetting property of rubber materials**
- **Hydrophobic - resists wetting by forming beads of water**
- **Hydrophilic - Surface wets out, films of water**
- **Silicone Rubber Units**
  - Hydrophobic
- **EP Rubber Units**
  - Hydrophilic
  - Could be hydrophobic initially



Grading rings

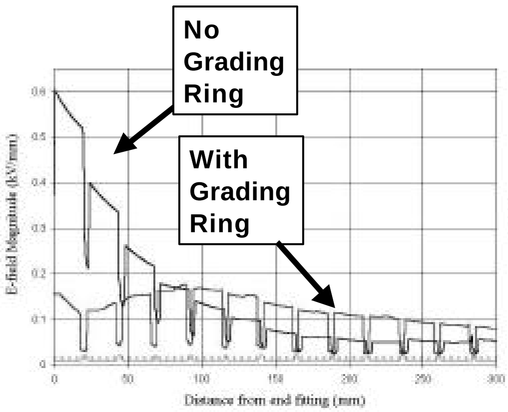
Energized End Grading Ring

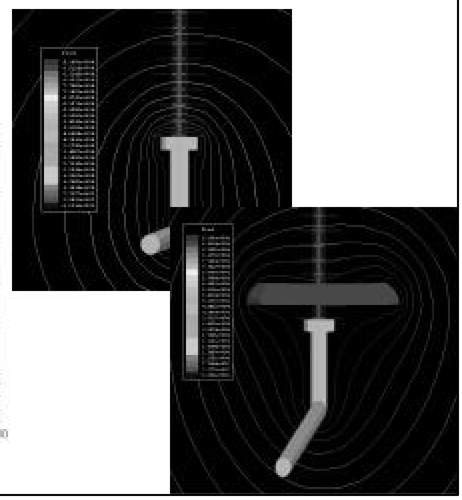


Grounded End Grading Ring

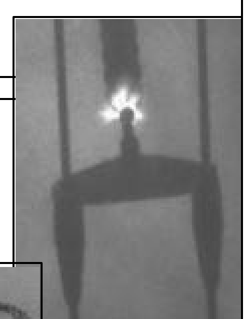
Grading Rings

- **Reduce E-field magnitudes at live and ground end fittings**





Why Grading Rings?



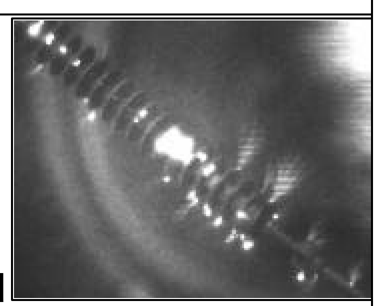
- **Prevent corona under dry conditions**
  - Radio interference, audio noise
- **Prevent internal discharge**
  - Voids & defects in rubber
- **Reduce wetting corona activity**
  - Ages rubber & end fitting seal

Wetting Corona Activity

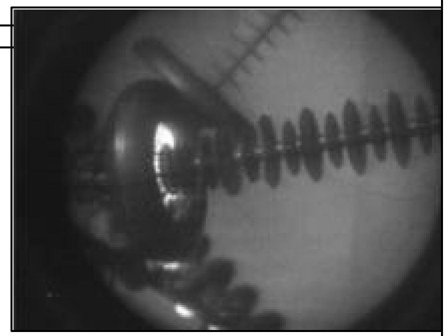
- **Result of:**
  - Non-uniform wetting
  - High E-field
- **Occurs mainly at live and ground ends**
- **Lower hydrophobicity makes discharge activity more likely**

Wetting Corona Activity

- **Is a function of:**
  - Type & magnitude of wetting
    - Hydrophobic/hydrophilic
    - Rain/mist/fog/condensation
  - Magnitude of surface E-field
    - Grading ring dimension and position
    - End fitting design
    - Configuration and live end hardware



Wetting Corona Aging Mechanism



- **Corona generates**
  - UV light
  - Heat
  - Gaseous by-products
    - 0_3 (Ozone), NO_2

$NO_2 + H_2O = HNO_3$ (Nitric Acid)

EPRI tests: Wetting on NCI lowers pH to 3.4 after 15 min. of wetting corona activity

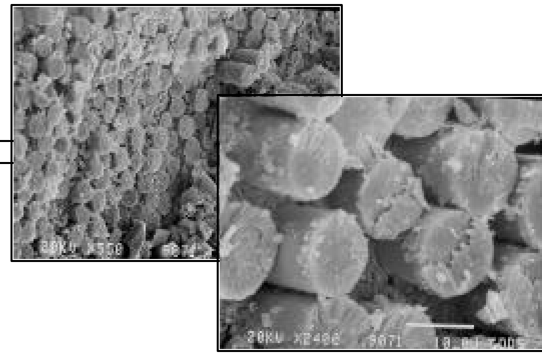
Failure Modes

- **Brittle fracture**
- **Failure of rod due to discharges**

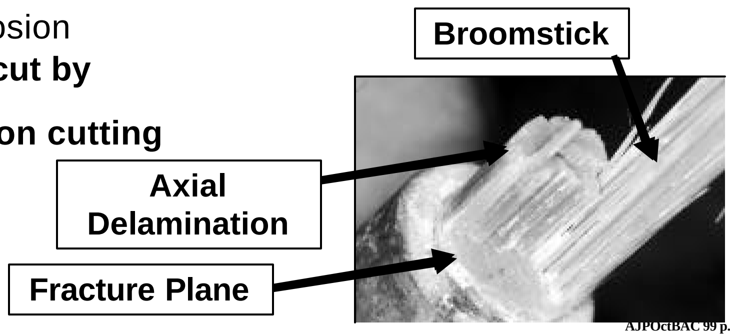
} **Water Reaches Rod**

- **Flash-under**
- **End fitting attachment**
- **Contamination flashover**
- **Mechanical failure of rod**

Brittle Fracture

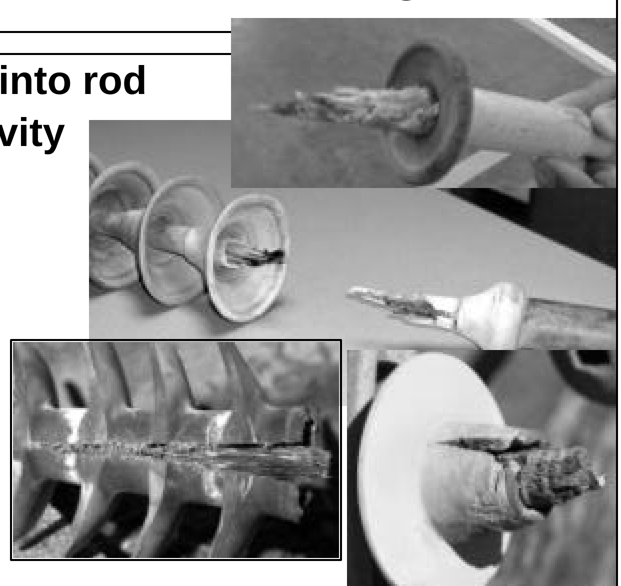


- **Water reached rod**
- **Acids form**
  - Discharge activity
  - Contaminants
  - Acid rain
  - Corrosion
- **Fibers cut by stress corrosion cutting**

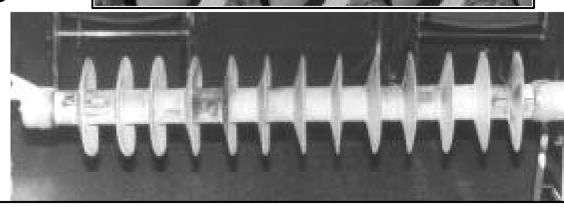


Failure of Rod Due to Discharges

- **Water ingress into rod**
- **Discharge activity degrades rod**
  - Chemically
  - Ionic wind
  - UV
  - Temperature
- **Rod fails under load**



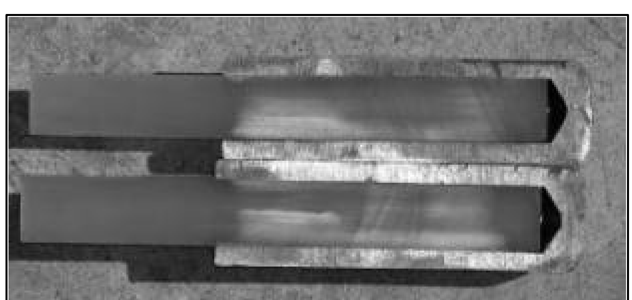
Flash-under



- **Water ingress**
- **Conductive path**
  - Through rod itself
  - On rod surface
- **NCI cannot hold voltage - flashover**
- **Power arc bursts through rubber**

End-fitting Attachment

- **Under crimping - pull out**
- **Over Crimping**
  - Cracked rod
  - May break with time



Contamination Flashover

- **Insulator becomes severely contaminated due to local environment**
- **Flashover may occur under critical wetting conditions**

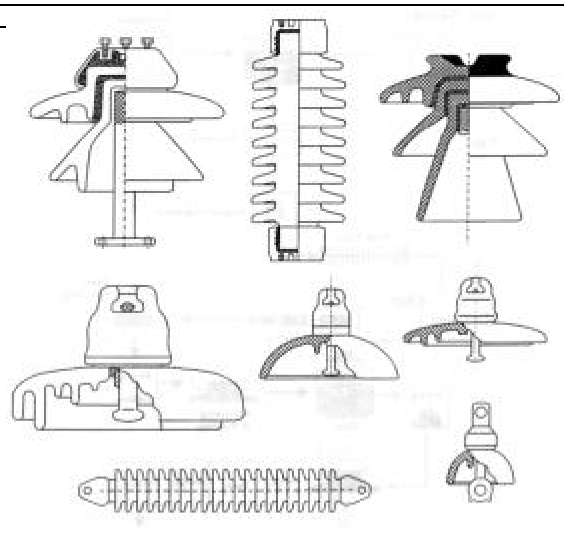
Mechanical Failure of Rod

- **Rod may fail mechanically in service due to:**
  - Poor rod manufacture
  - Mishandling during shipping or installation
    - Severe torsion
    - Severe bending
  - Mistreatment during manufacture
  - Overloading

Issues with Polymers

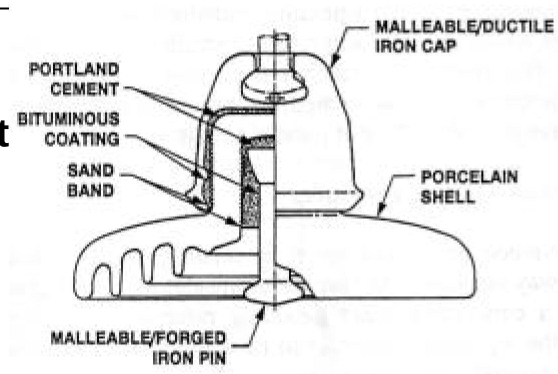
- Aging of Polymer Materials
- Limited Experience
- Large Variation in designs, materials and manufacturing techniques
- Handling concerns
  - Storing, transporting and installing

Ceramic Insulators Types



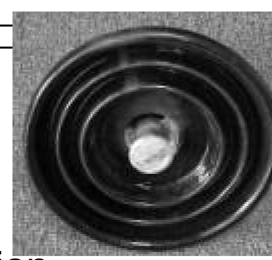
Porcelain Cap & Pin Insulators Basic Components

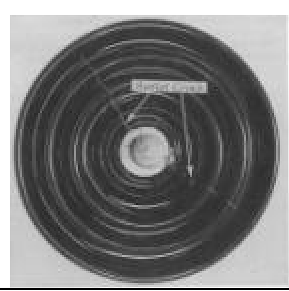
- Porcelain Shell
- Portland Cement
- Hardware



Issues with Ceramic Insulators

- Flashovers
- Punctures
- Cement Growth Cracking
- Pin erosion
- Long Term M&E Strength Reduction
- Coupling Hardware Corrosion





Ceramic vs. Polymers

Ceramics

- Made from Inorganic materials
  - Do not age
- >80 years of experience
- Flexibility in Length
- High Leakage Distance Profiles
- Can be coated & washed

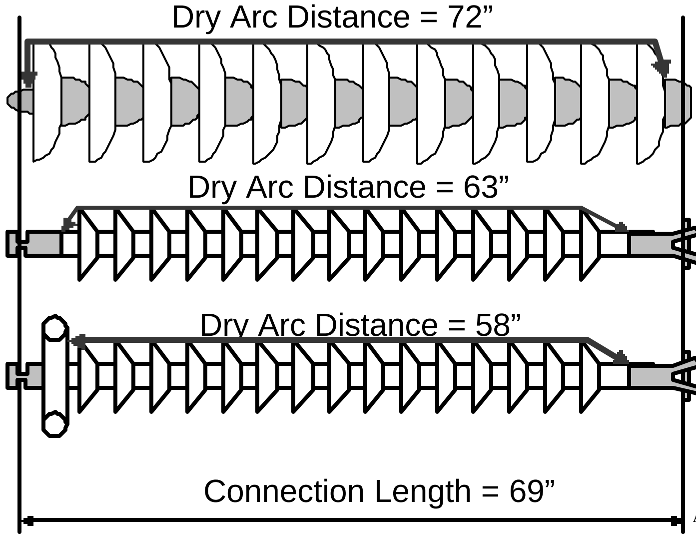
Polymers

- Made from Organic Materials
  - Age
- > 30 years experience
  - Latest designs < 10 years
- Lighter
- Less susceptible to vandalism
- Smaller Viewing Profile
- Good short term performance in polluted environments

Polymers vs. Ceramic Weight

Item	Type	Voltage (kV)	Ceramic Weight (lbs)	Polymer Weight (lbs)	Weight Reduction (lbs)
Insulator	Dist.	15	9.5	2.4	74.7
Arrester	Dist.	15	6.0	3.8	36.7
Post Insulator	Trans.	69	82.5	27.2	67.0
Suspension Insulator	Trans.	138	119.0	8.0	93.2
Intermediate Arrestor	Subs.	69	124.0	28.0	77.4
Station Arrester	Subs.	138	280.0	98.9	64.7

Ceramic vs. Polymer
Dry Arc Distance



Polymer vs. Ceramic
Connection Length & Dry Arc Distance

- **For the same connection Length Polymers have shorter Dry Arc Distances**

Example for 12 Bell Equivalent

	Voltage Level	Connection Length	Dry Arc	AC flashover		Critical Impulse	
				Dry	Wet	+ve	-ve
Ceramic	230 kV	69”	72”	690kV	490kV	1105kV	1105 kV
Polymer	230 kV	69”	58.4”	585kV	510 kV	945kV	970kV
Reduction	**0%**	**0%**	**-19%**	**-15%**	**+4%**	**-15%**	**-12%**

- **Therefore: One needs to be careful when replacing a Ceramic with a Polymer!!**

***Note: Example for one specific polymer manufacturer and 5 ¾“ Bells**

Electrical design

Requirements for 138 kV

Voltage Level	60 Hz Low Freq. Dry	60 Hz Low Freq. Wet	Impulse +ve	Impulse -ve	Contamination Level	Specific Leakage Distance
138 kV	390kV (NESC)		741 kV	722 kV	Low	16 mm/kV

Ceramic

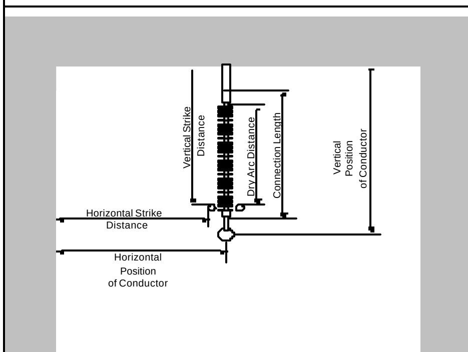
No of Bells	Connect Length	60 Hz Low Freq. Dry	60 Hz Low Freq. Wet	Impulse +ve	Impulse -ve	Leakage Distance	Specific Leakage Distance
7 bells	42.5 "	435 kV	295 kV	695 kV	670 kV	2.04 m	15 mm/kV
8 bells	**46.0"**	**485 kV**	**335 kV**	**780 kV**	**760kV**	**2.34 m**	**17 mm/kV**
9 bells	51.7"	540 kV	375 kV	860 kV	845 kV	2.63 m	19 mm/kV

Polymer

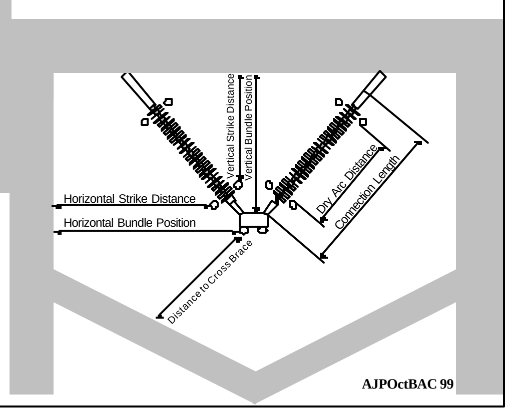
Polymer	Connect Length	60 Hz Low Freq. Dry	60 Hz Low Freq. Wet	Impulse +ve	Impulse -ve	Leakage Distance	Specific Leakage Distance
P 1	47.4 "	390 kV	320 kV	605 kV	635 kV	2.53 m	18 mm/kV
P 2	49.5"	410 kV	340 kV	640 kV	670kV	2.68 m	19 mm/kV
P3	53.9"	450 kV	380 kV	710 kV	735 kV	2.99 m	22 mm/kV
P4	**58.2"**	**490 KV**	**415 kV**	**780 kV**	**805 kV**	**3.30m**	**24 mm/kV**

AJPOctBAC 99 p.-31

Polymer vs. Ceramic
Strike Distance



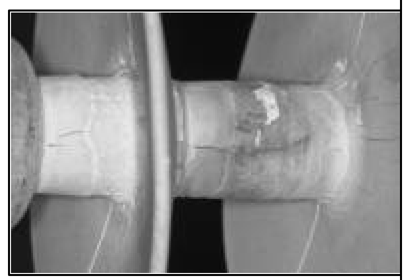
One needs to be careful when replacing a Ceramic with a Polymer!!



AJPOctBAC 99

Polymer vs. Ceramic
Aging of Polymers

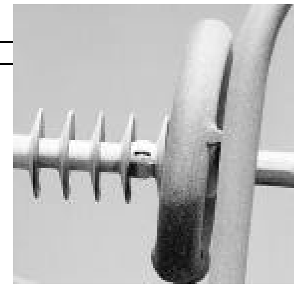
- **Polymers made from Organic Materials**
  - Rubber & Fiberglass
- **Materials age with exposure to environment**
  - UV, rain, contamination, mist, E-fields
- **Different polymers age differently**
  - Different manufacturers
  - Different material types
  - Environment
- **Experience with new Polymers & Processes is limited**
  - Designs used today are from the early to late 90's
  - Less than 12 years experience



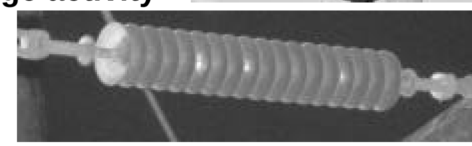
Polymer vs. Ceramic
Performance under contaminated conditions

- **EPDM Polymers appear to perform similarly ceramic insulators in flashover tests**
- **SIR Polymers appear to perform better than ceramic insulators (in flashover tests)**
  - Material properties (SIR – hydrophobicity)
- **In some cases Polymers have been found in to perform better than ceramic**
  - Short term – SIR definitely
  - Long term – jury still out

Polymer vs. Ceramic
Performance under contaminated conditions EPDM



- **Aged EPDM perform similarly or worse than to ceramic in flashover tests**
  - Aging of rubber material
- **Rubber material can become aged & degraded - continual discharge activity**
  - Dry Band Arcing
  - Leakage Currents



- **Results in**
  - Flashovers
  - Material degradation
    - cracking, rod exposure, tracking
  - Line Droppings

Polymer vs. Ceramic
Performance under contaminated conditions SIR

- **Aged SIR can perform better than ceramic (in flashover tests)**
  - Material can become overwhelmed
    - Lower Hydrophobicity
    - Flashovers
  - Degradation
    - Tracking
    - Rod Exposure

•**Short-term definite improvements**

•**Long-term can be a problem**

•***both good & bad experiences***

Polymer vs. NCI
Mechanical Ratings - Suspension

Ceramic Insulators

- **Mechanical & Electrical Rating (M&E)**

Mechanical Load at which the Insulator Bell stops functioning either:

- **Mechanically** or
- **Electrically**

- **Every unit tested to a load of 50% of M&E rating for 10 secs.**
- **Every unit electrically tested (after or simultaneously with the mechanical test)**
- **Units applied**
  - < 20% of M&E rating for everyday load
  - < 50% of M&E rating for maximum loads

Polymer vs. NCI
Mechanical Ratings- Suspension

Polymer Insulators

- **Specific Mechanical load (SML)**

Mechanical Load that a Polymer can hold for 60 seconds without failing

- **Every unit tested @ 50% of SML for 60-90 secs**
  - **Routine Test Load (RTL)**
  - **No electrical stress applied**
- **Units applied**
  - < 20% of SML rating for everyday load
  - < 50% of SML rating for maximum loads

Porcelain vs. Glass vs. Polymer

Type	Pros	Cons	Issues
Polymers	Lightweight & Easier to Handle "Reduced Installed Cost" Improved contamination performance Smaller profile	Reduced Dry Arc Distance Susceptible to arcing damage due to flashovers Lack of standard dimensions Relatively "limited" experience Difficult to inspect Damaged by Corona Activity, etc,	Susceptible to aging Prone to handling damage Grading rings Contamination performance changes with time Brittle Fracture
Porcelain	Inert surface Performance well quantified Puncture of a single unit does not take out a string Long history of use Damaged units easier to identify Flexible in Length (# of units)	Heavy and cumbersome Hidden defects Fun to shoot	Pin corrosion Cement growth Post cascade failures
Glass	Performance well quantified Long history of use Easy to identify damaged unit Flexible in Length (# of units)	Heavy and cumbersome Real Fun to shoot	Surface defects – failure

EPRI Related Research

- **Aging of Polymer Insulators**
  - 500 kV Full Scale Aging Test
    - Report Prod ID# 100719
  - 230 kV Full Scale Aging Test

Insulator Related Guides

- Application Guide for Transmission Line NCI – TR 111-566
- Guide to Visual Inspection of NCI – 10000998
- Guide to Corona & Arcing Inspection of OHT Lines – 1001910
- Educational Video “Storing, Transporting & Installing Polymer Insulators – 1006353
- Storing, Transporting & Installing Polymer Insulators: An Practical Guide

Other Research Reports

- E-field Modeling of NCI and Grading Ring Design & Application – TR 113-977
- Effect of High Temperature Operation on NCI – Product Id# 1000033
- Electrical & Mechanical Performance of Ceramic Insulators – 1000505
- Fracture Analysis of Polymer Insulators - 1006293

Ongoing research

- End fitting Performance and Design
- Evaluation of In-service Insulators
- Development of In-service Inspection Tools
- Industry Survey on experience with Polymers – 71 utilities
- Failure Database – 3 years in the making

If you have had any failures @ voltages $\geq$ 69 kV please send a note to aphillip@epri.com