ELECTRIC POWER
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Water Trees:
Some thoughts for Diagnosticians II

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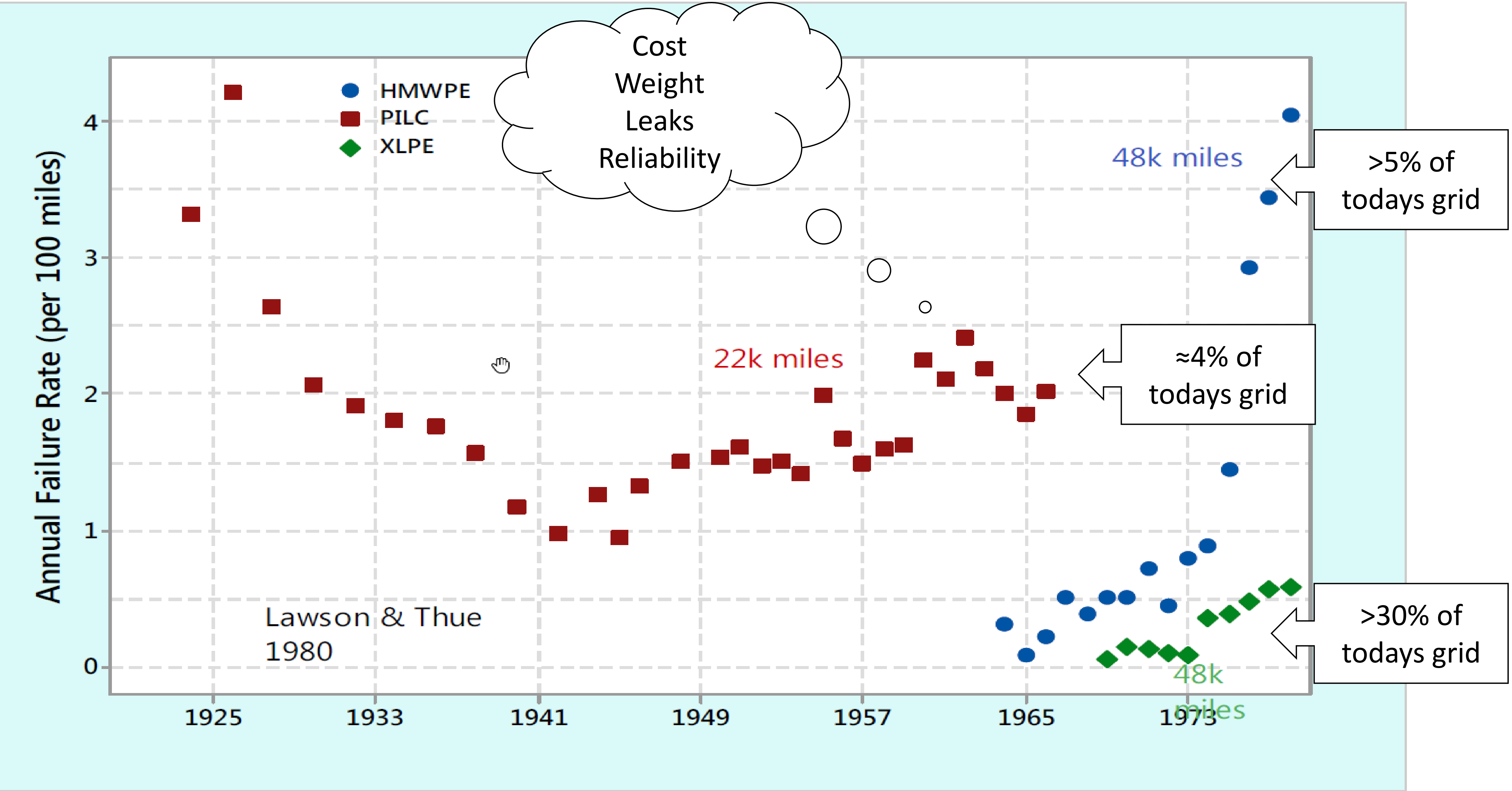
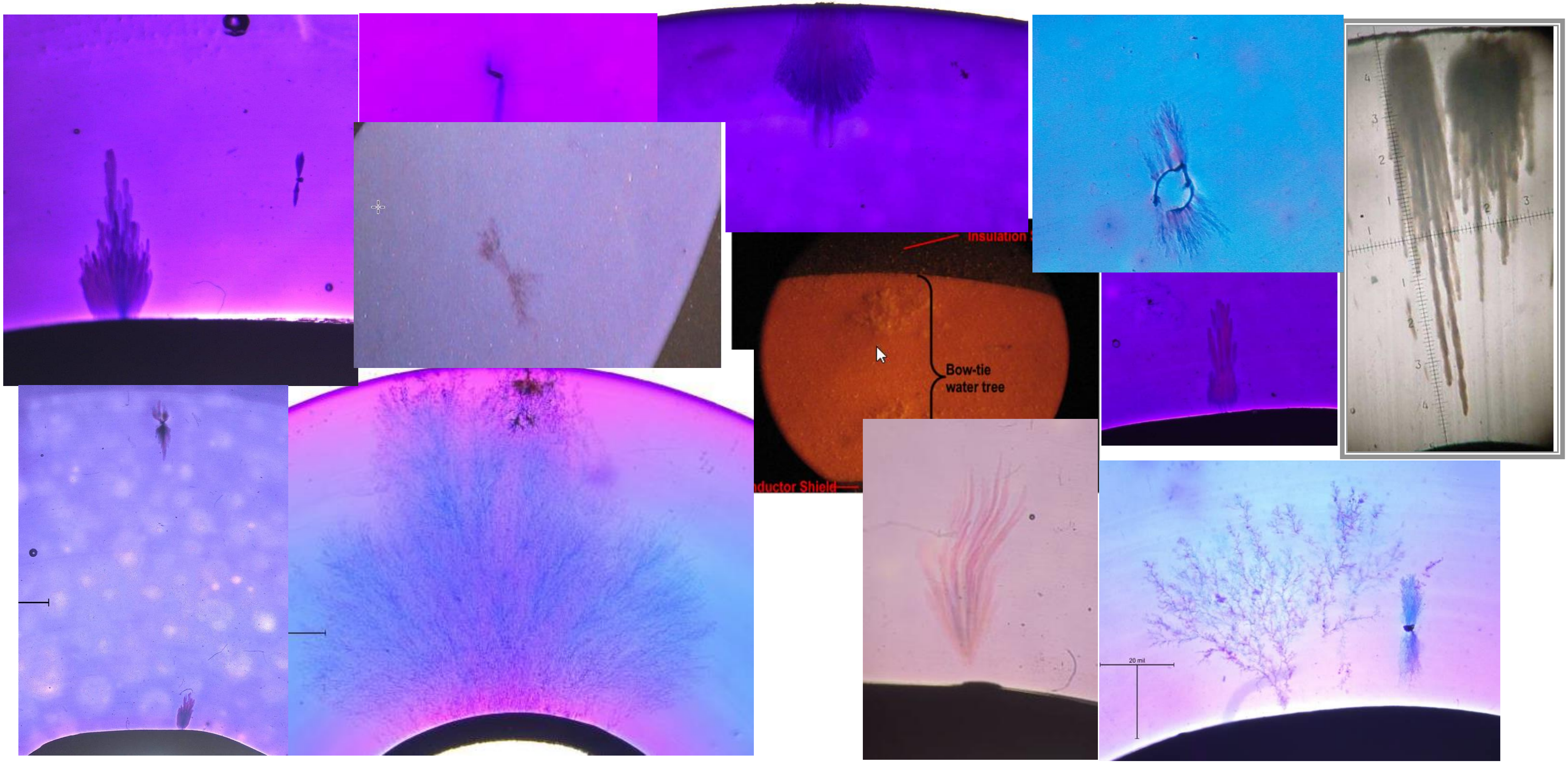
Background

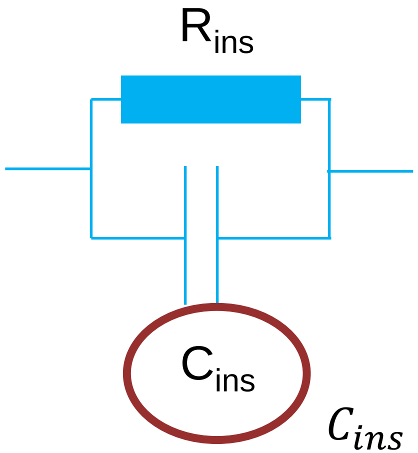


Cost
Weight
Leaks
Reliability
HMWPE
PILC
XLPE
Annual Failure Rate (per 100 miles)
0
1
2
3
4
1925
1933
1941
1949
1957
1965
1973
Lawson & Thue
1980
22k miles
48k miles
48k
miles
>5% of
todays grid
≈4% of
todays grid
>30% of
todays grid

Water Trees observed in EPR, HMWPE, WTRXLPE, XLPE



Water Trees & Electrical Stress

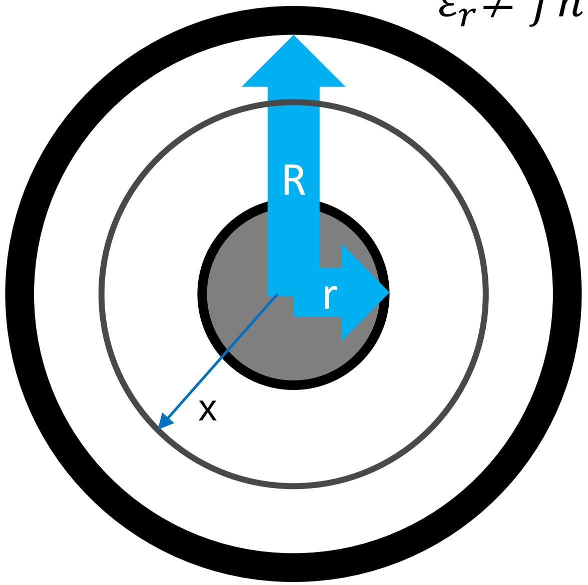


Actual stress at distance x from the center of the cable:

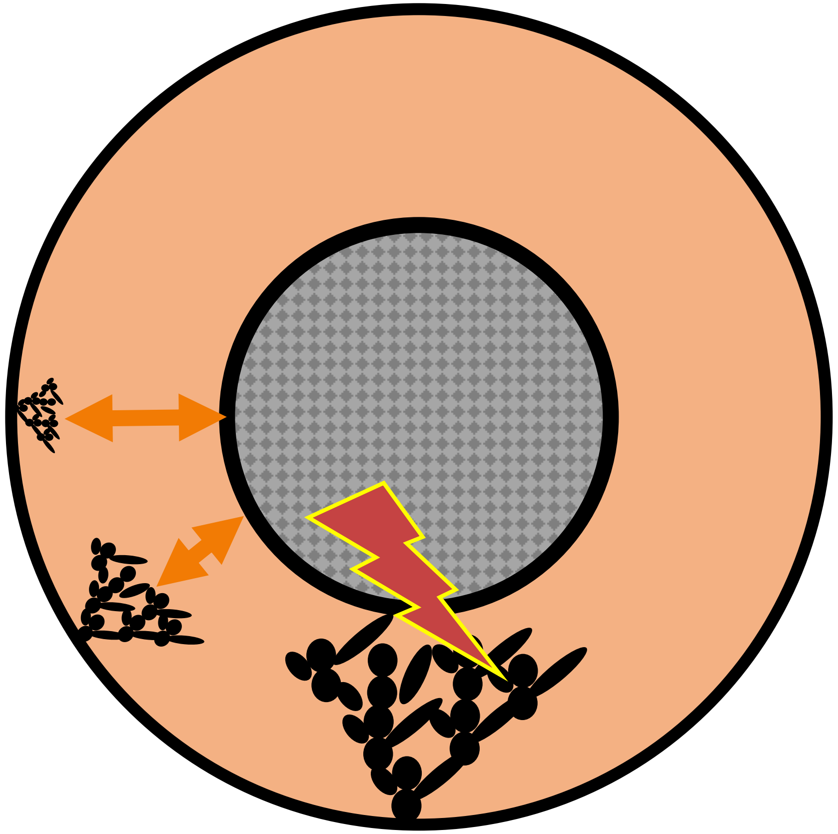
$$V = \int_R^r -E_x dx$$

$$V = \frac{-q}{2\pi\varepsilon}\int_R^r \frac{dx}{x}$$

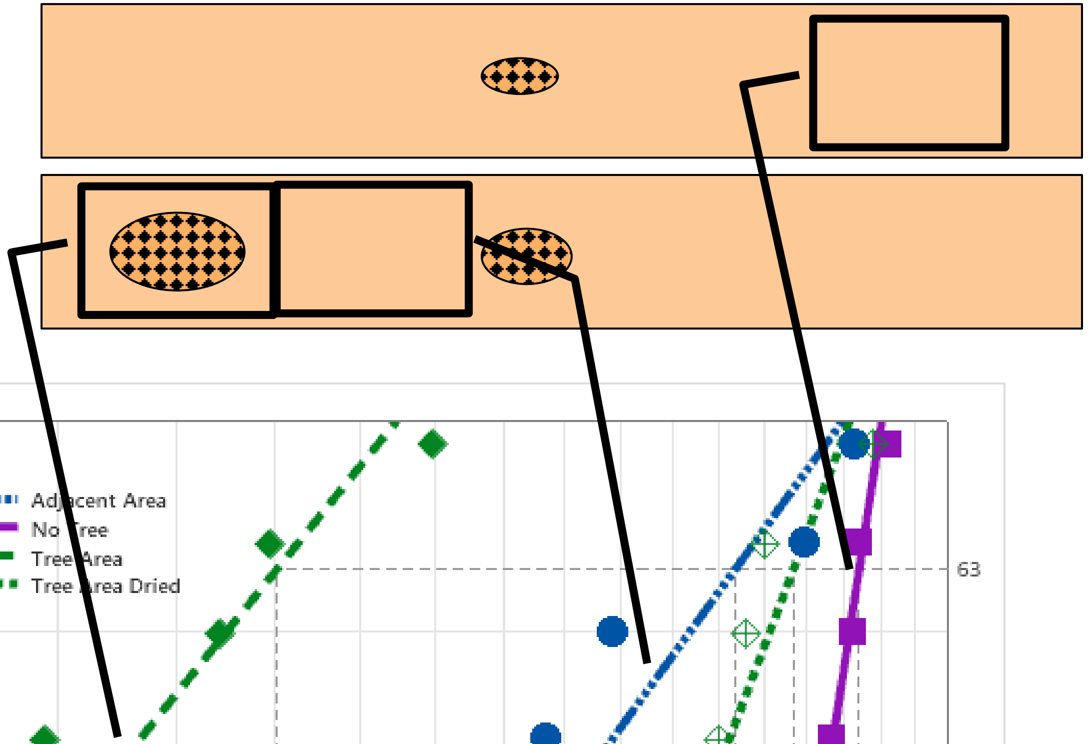
$$C_{ins} \propto \varepsilon_r,$$
$$\varepsilon_r \neq fn(x)$$
$$\varepsilon_r \neq fn(T)$$

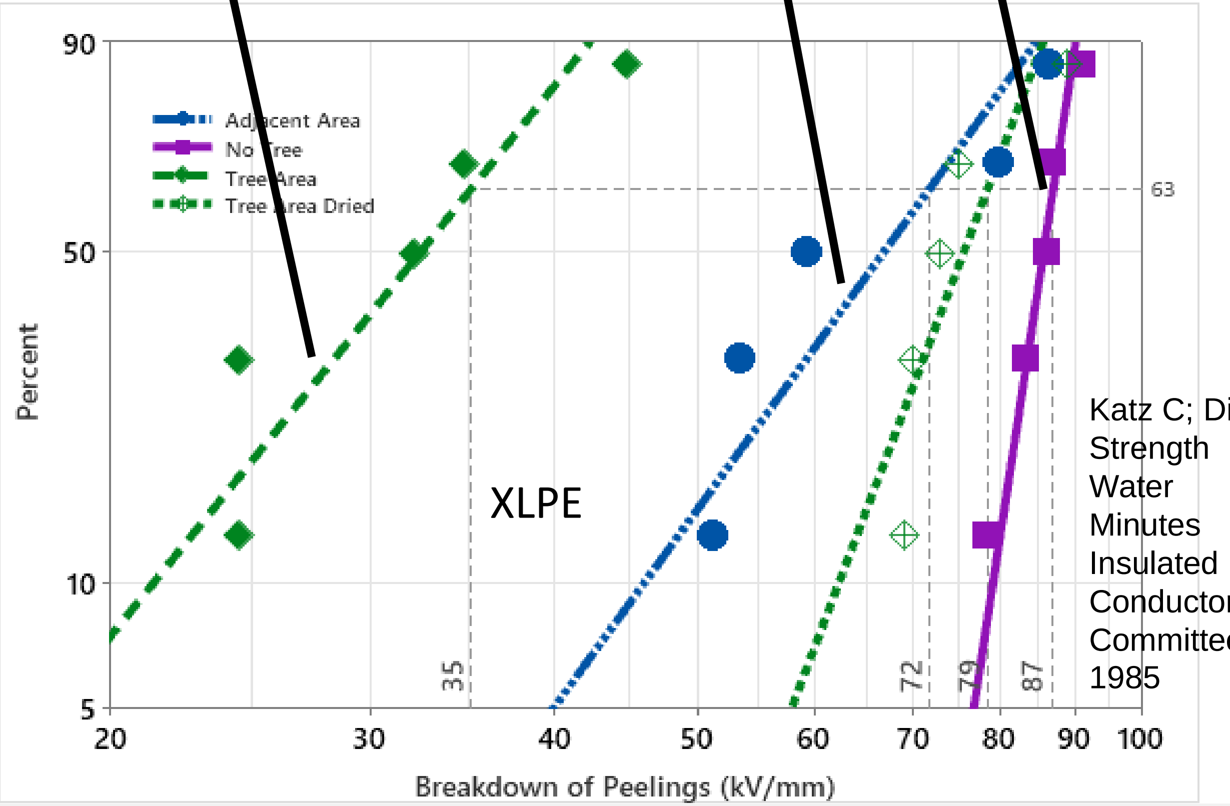


$$E_x = \frac{V}{x \ln\frac{R}{r}}$$ kV/mm or V/mil

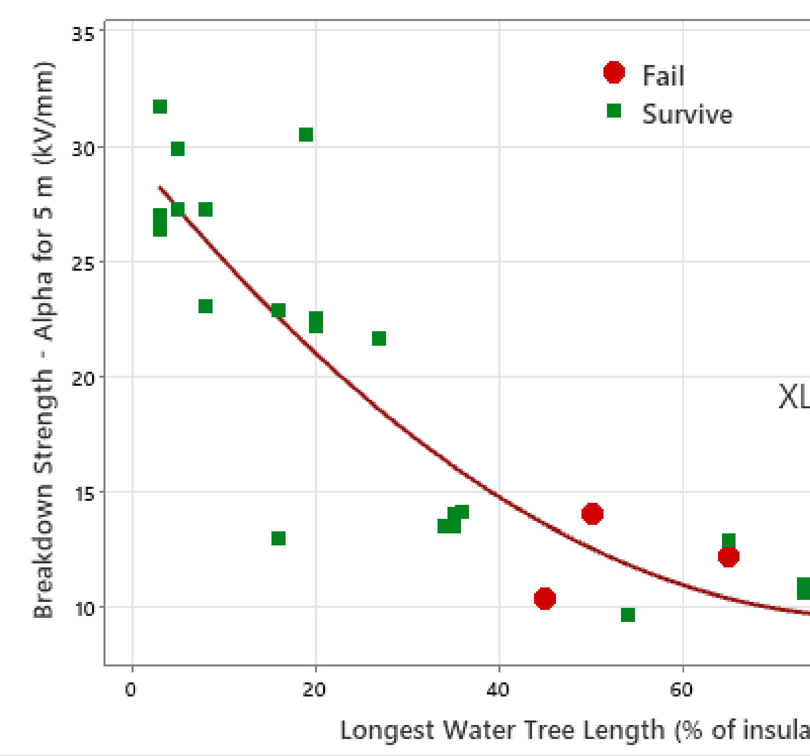


Strength with Water Trees

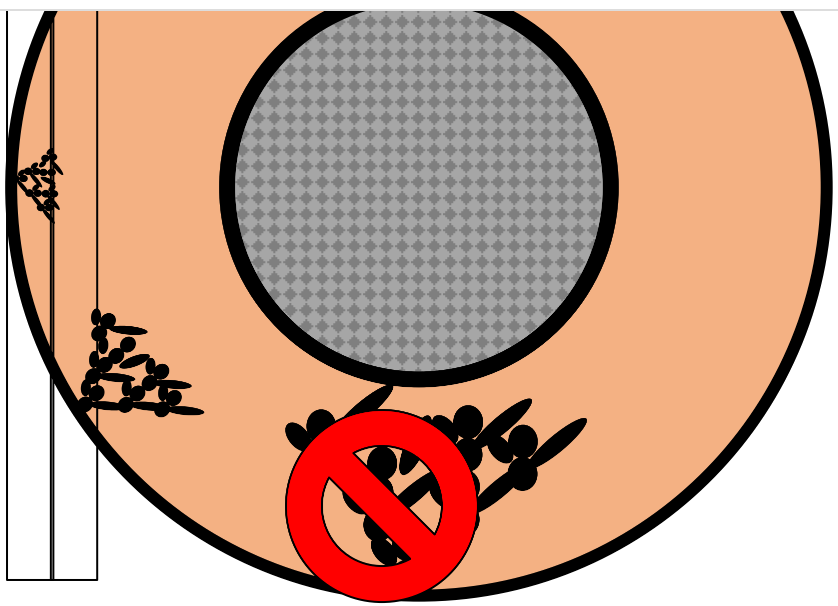




Katz C; Dielectric Strength of Water Trees, Minutes of Insulated Conductors Committee Nov 1985

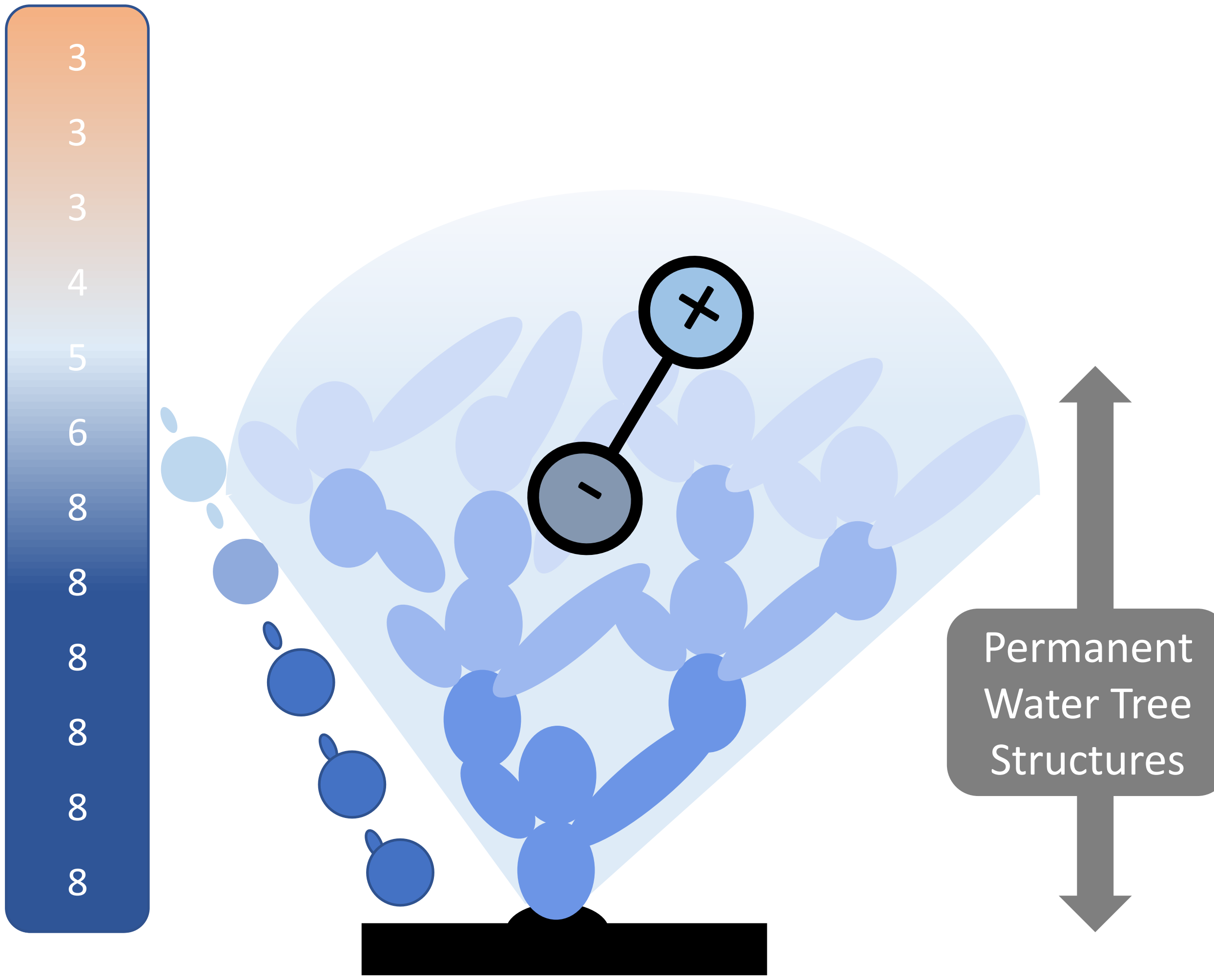


Steennis, E.F., “Water treeing – the behaviour of water trees in extruded cable insulation”, 1990; ISBN 90-353-1022-5 132 – 133

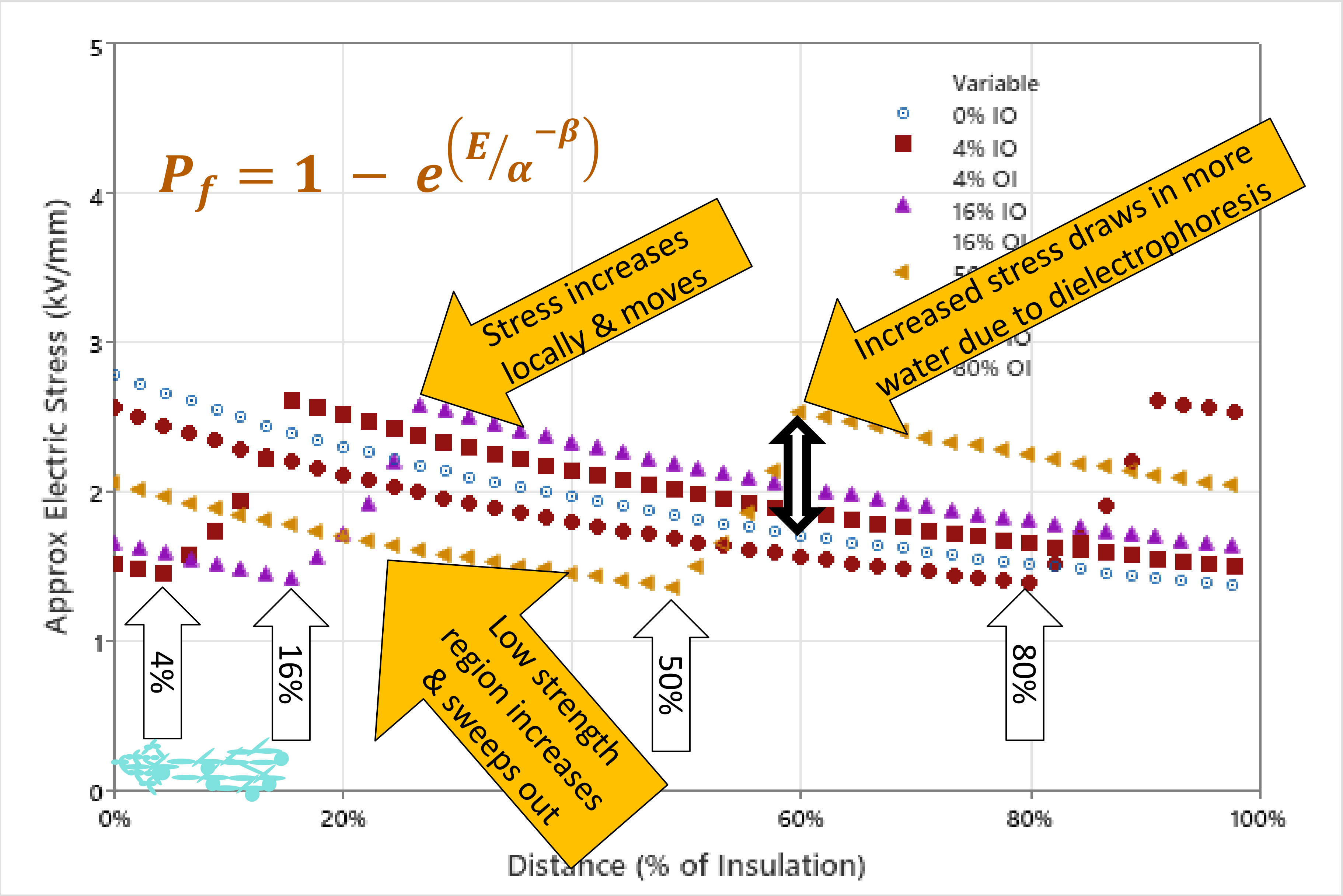


	Permittivity
XLPE	2.5–2.8
EPR	3–3.5
Water	80
Water tree	5–8

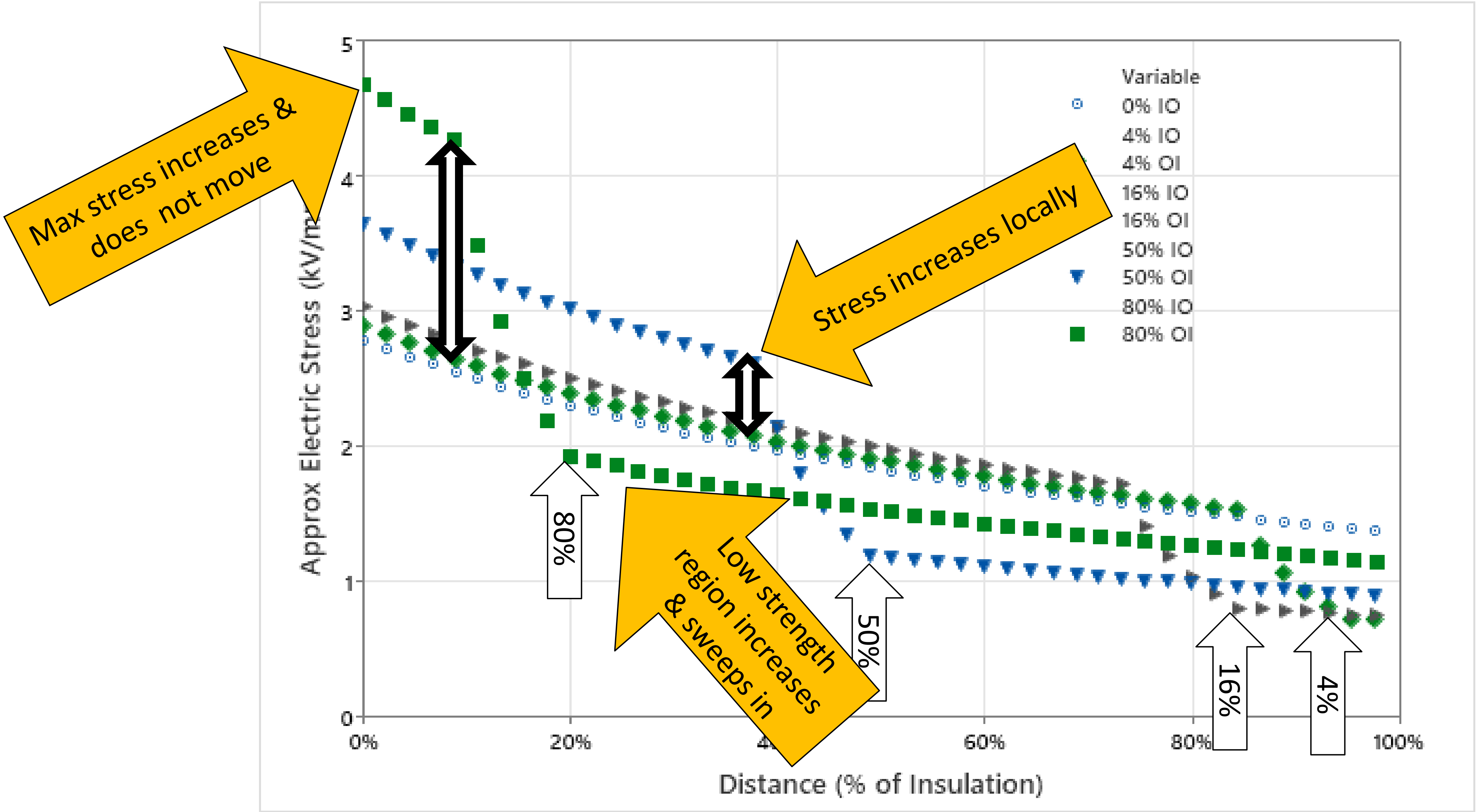
$$E_x \propto C_{ins} \propto \varepsilon_r,$$
$$\varepsilon_r = fn(x)$$
$$E_x \neq \frac{V}{x \ln \frac{R}{r}}$$



Water Trees Growing Inside Out

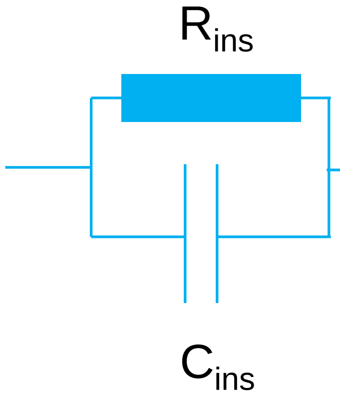


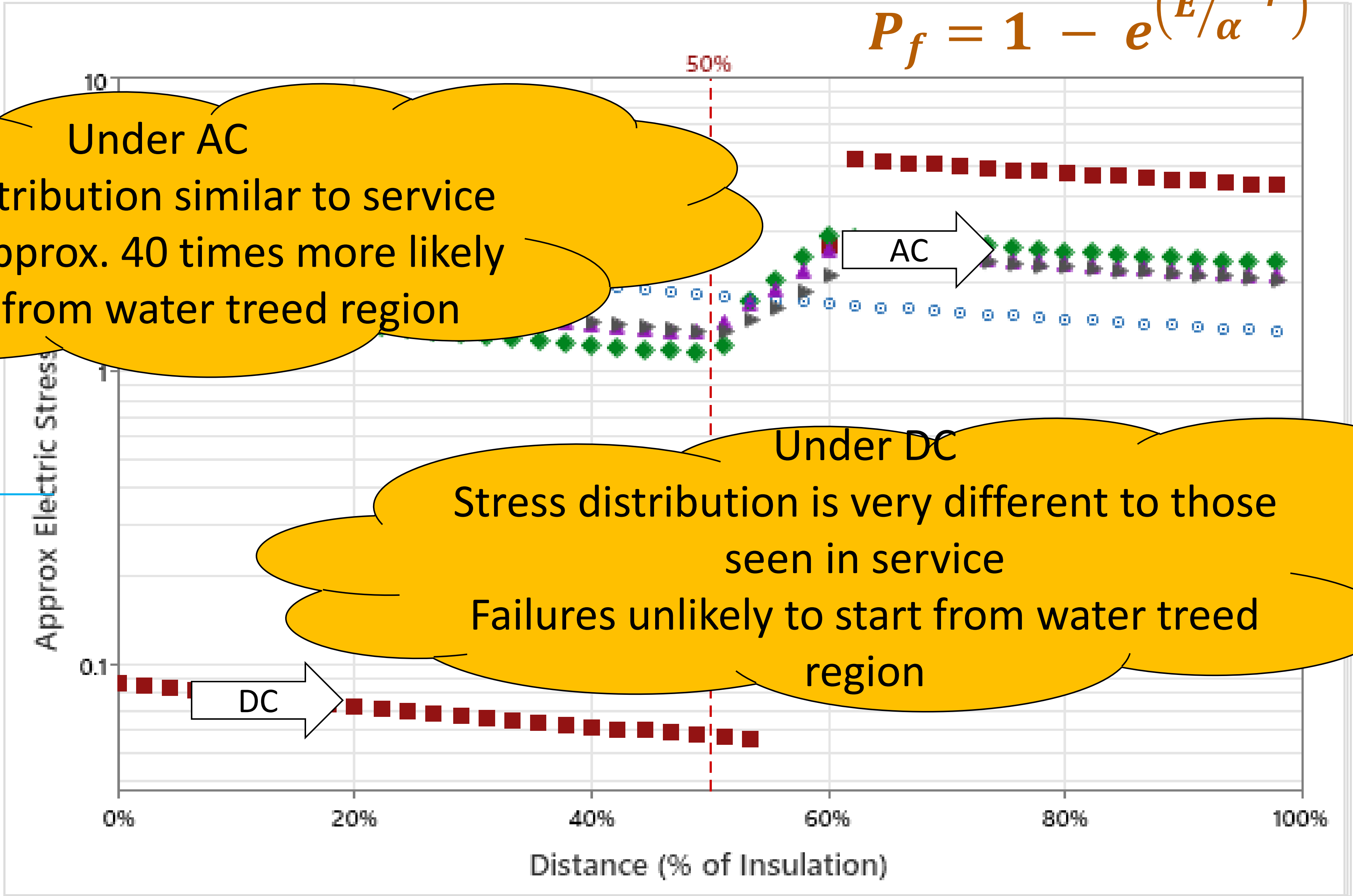
Water Trees Growing Outside In



AC & DC Waveforms

$$P_f = 1 - e^{\left(E/\alpha^{-\beta}\right)}$$



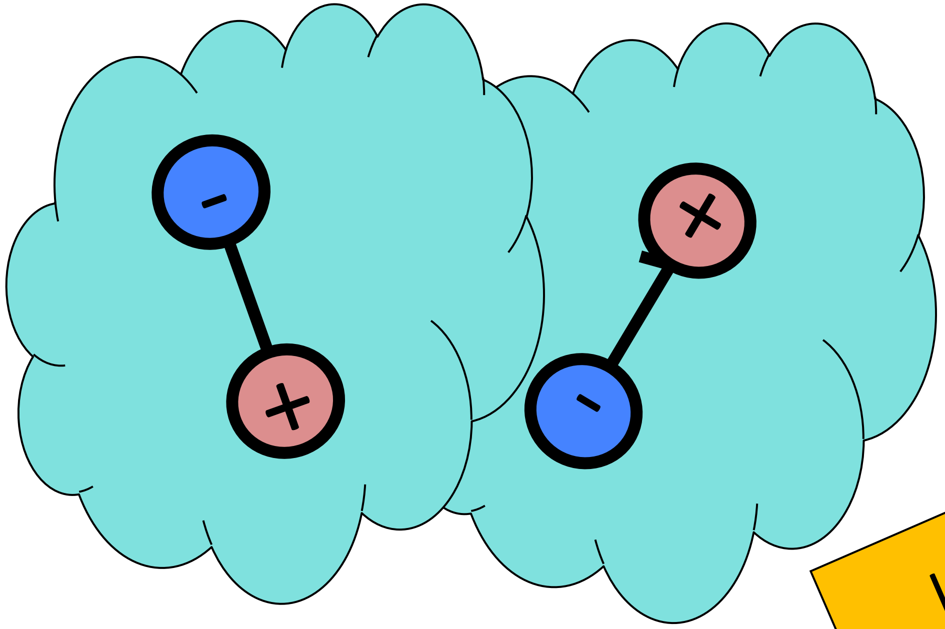


Under AC
Stress distribution similar to service
Failures approx. 40 times more likely to start from water treed region

Under DC
Stress distribution is very different to those seen in service
Failures unlikely to start from water treed region

Dielectric Measurements

- The volume of insulation affected and the density of trees impacts the measured Tan Delta
- The Stability and the Tip Up are likely impacted by the local heating within the Water Tree via σ

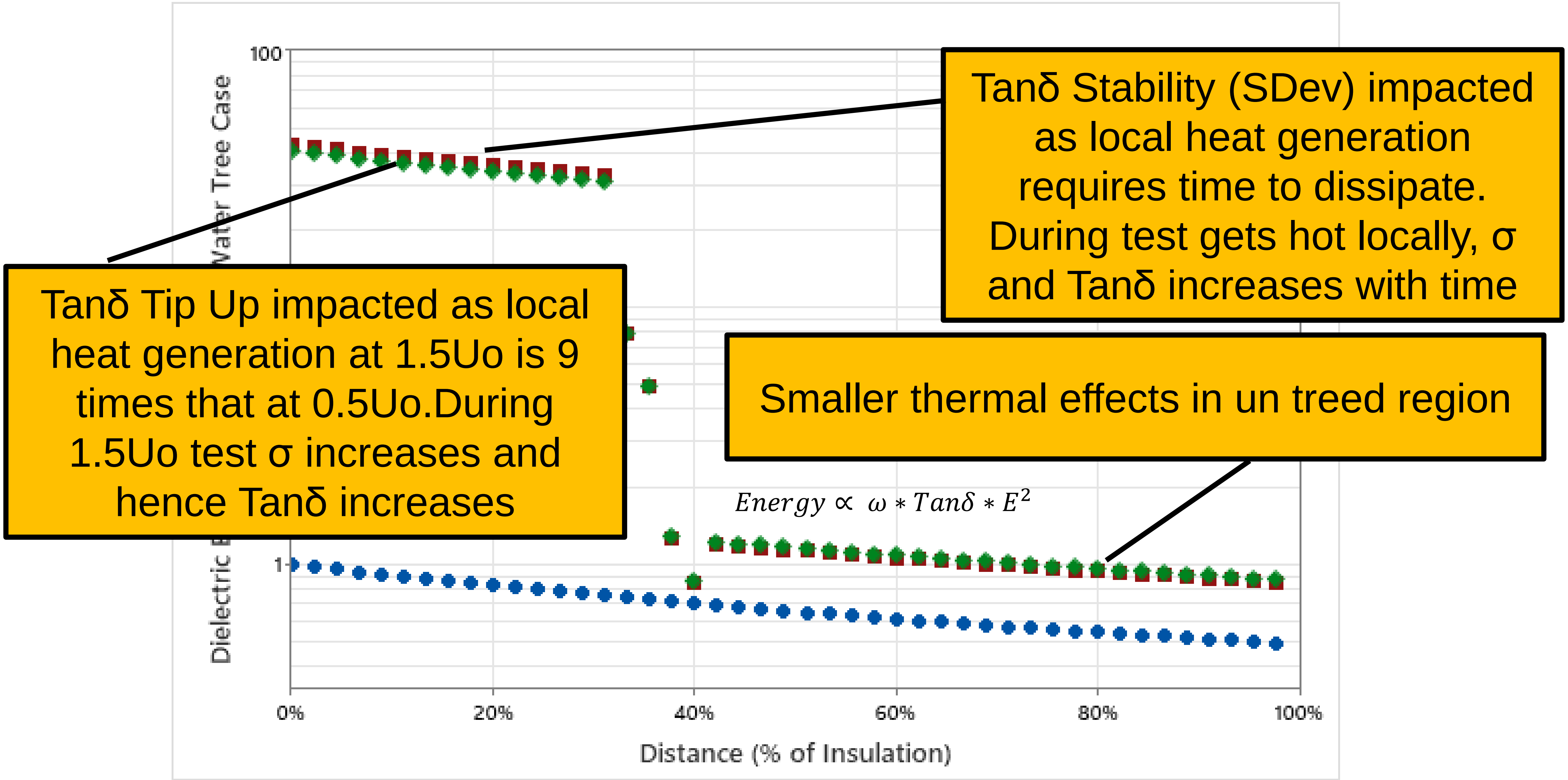


$$Energy \propto \ldots * Tan\delta * E^2$$

Increased in the Water Treed regions; depends upon local ε & σ

Decreased in the Water Treed regions

Energy generated in the Dielectric



To Wrap Up

- Water Trees are not structures that simply form a conducting bridge across the insulation
- They are complex dielectric features that interact with the accessory / cable dielectric
- How and where trees grow impacts our ability to detect them
- Water Trees grown in the lab are different (density & length) to the Trees that grow in service – large lab trees are 6% to 8% of insulation
- Physical basis why Tan δ SDev and Tan δ TU are seen to be powerful diagnostic features

- Nigel Hampton has more than 30 years of experience in the MV & HV cable field at BICC in the United Kingdom, Borealis in Sweden, NEETRAC, UL Solutions and currently EPRI in the United States. Nigel currently Chairs IEEE400.0 Field Testing Techniques and IEEE400.2 Field Testing using VLF Sources. Nigel has served as the Technical Advisor to the AEIC Cable Engineering Committee since 2008.