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Taipei Chapter

High Frequency Voltage Stress

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2.10.1.1 Frequency

The insulation requirements given in 2.10 are for frequencies up to 30 kHz. It is permitted to use the same requirements for insulation operating at frequencies over 30 kHz until additional data is available.

10 Insulation requirements

The insulation requirements given in this standard are for frequencies up to 30 kHz. It is permitted to use the same requirements for insulation operating at frequencies over 30 kHz until additional data are available.

Now the additional data is available!

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ground rules:

1. **intro to PD.**
2. **experimental results.**
3. **comparison** with current practice.
4. **why** different?
5. **how air** and **solid** dielectrics behave under high frequency stress?

IEC 60664-4:2005 (2nd Ed.)

- Any type of periodic voltages with a **fundamental frequency** (f_0) above 30 kHz and up to 10 MHz

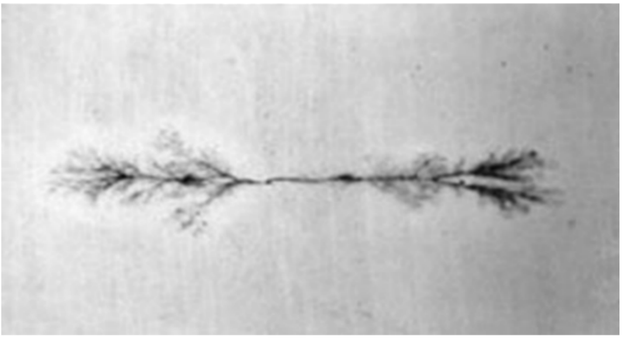
Key phenomenon = **partial discharge (PD)**

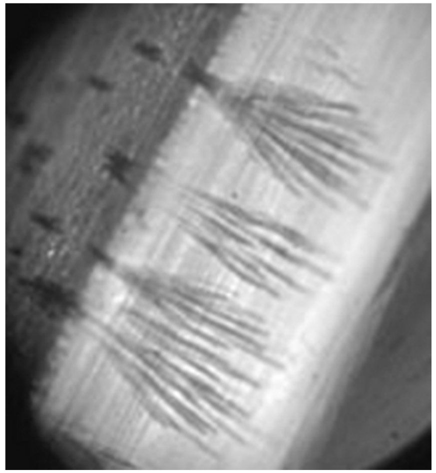
- Its deteriorating effect is aggravated roughly in proportionally to the frequency

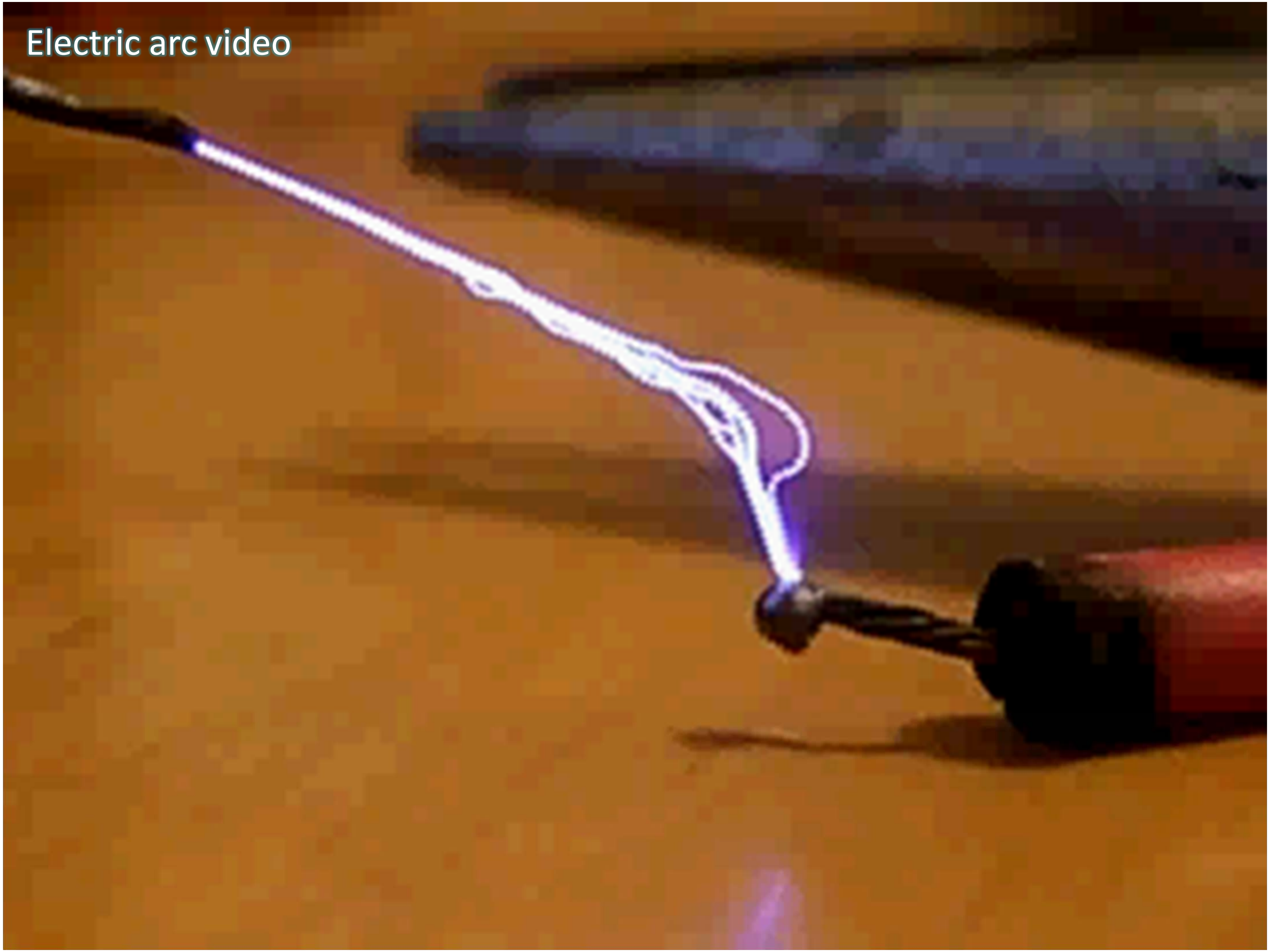
partial discharge (PD)

is a localized discharge within a solid or fluid dielectric system, restricted to only a part of dielectric material thus ***only partially bridging the electrodes***, and is typically observed:

- in cavities, voids (bubbles) or gaps;
- between interfaces of different dielectric properties;
- at sharp electrode edges or protrusions.






Electric arc video


V
dark discharge
glow discharge
arc discharge
Townsend regions
normal glow
abnormal glow
non-thermal
thermal
breakdown voltage
corona
saturation
background
glow-to-arc transition
nA
µA
mA
A
kA
I

Slow motion video of lightning

CLEARANCES

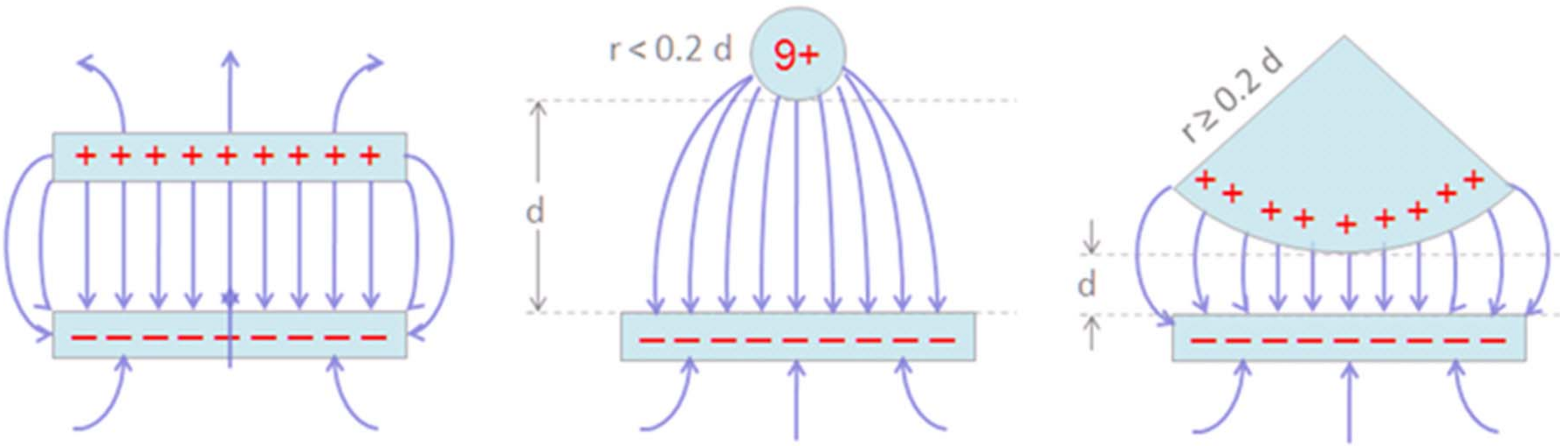
field homogeneity

inhomogeneous field (point-to-plane)..................Case **A**

homogeneous field (plane-to-plane)................. ....Case **B**

approximately homogeneous field

- when the radius of curvature of the conductive parts is equal or greater than **20 %** of the associated clearance.



Homogeneous Field (Case B)

Inhomogeneous Field (Case A)

Approximately Homogeneous Field

figure A.1 — breakdown at high frequency in air at atmospheric pressure, homogeneous field, 50 Hz – 25 MHz

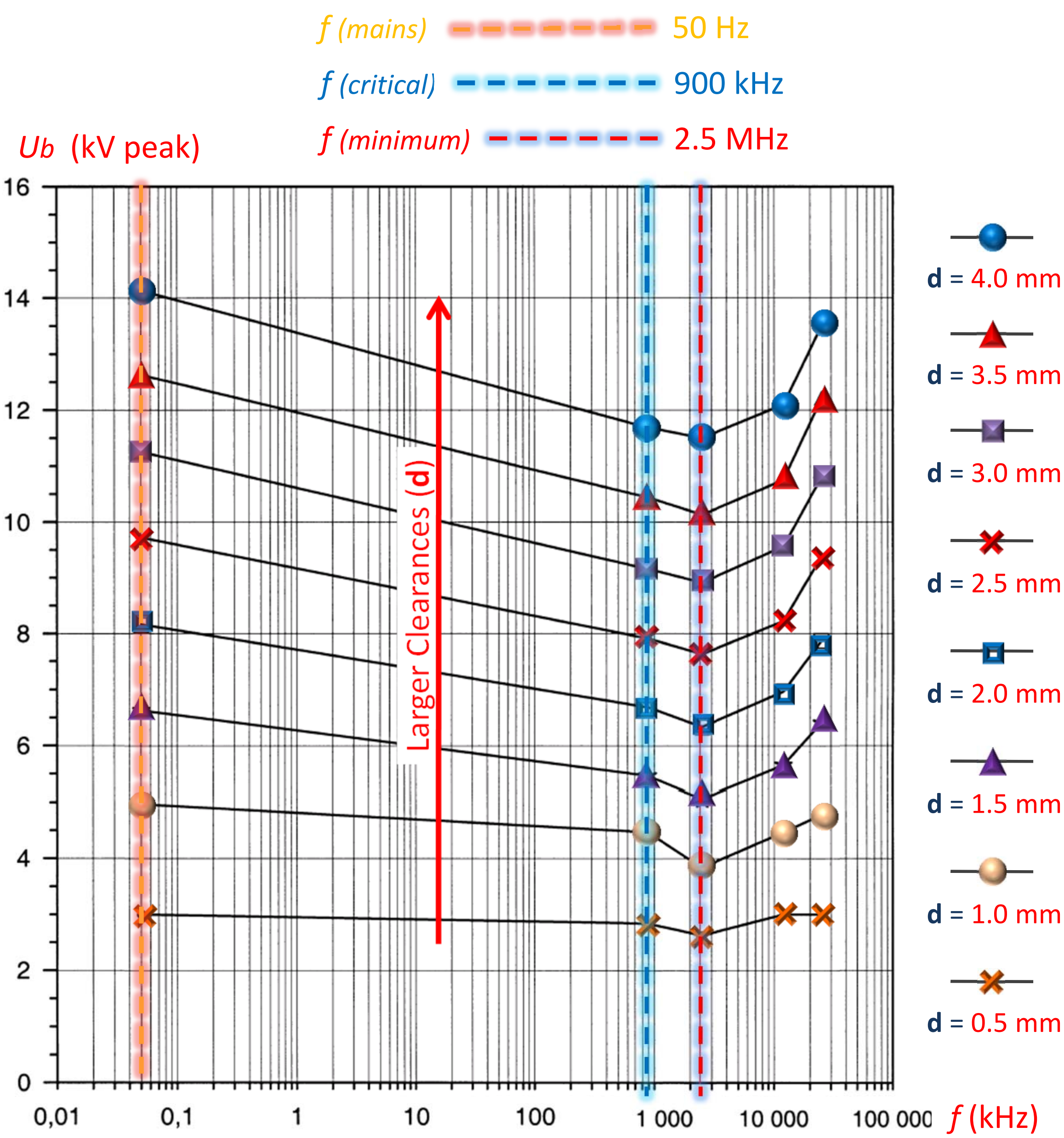
breakdown voltage (U_b) is frequency-dependent.

U_b degrades at 900 kHz, i.e., critical frequency.

worst-case scenario at 2.5 MHz, i.e., $f_{(min)}$

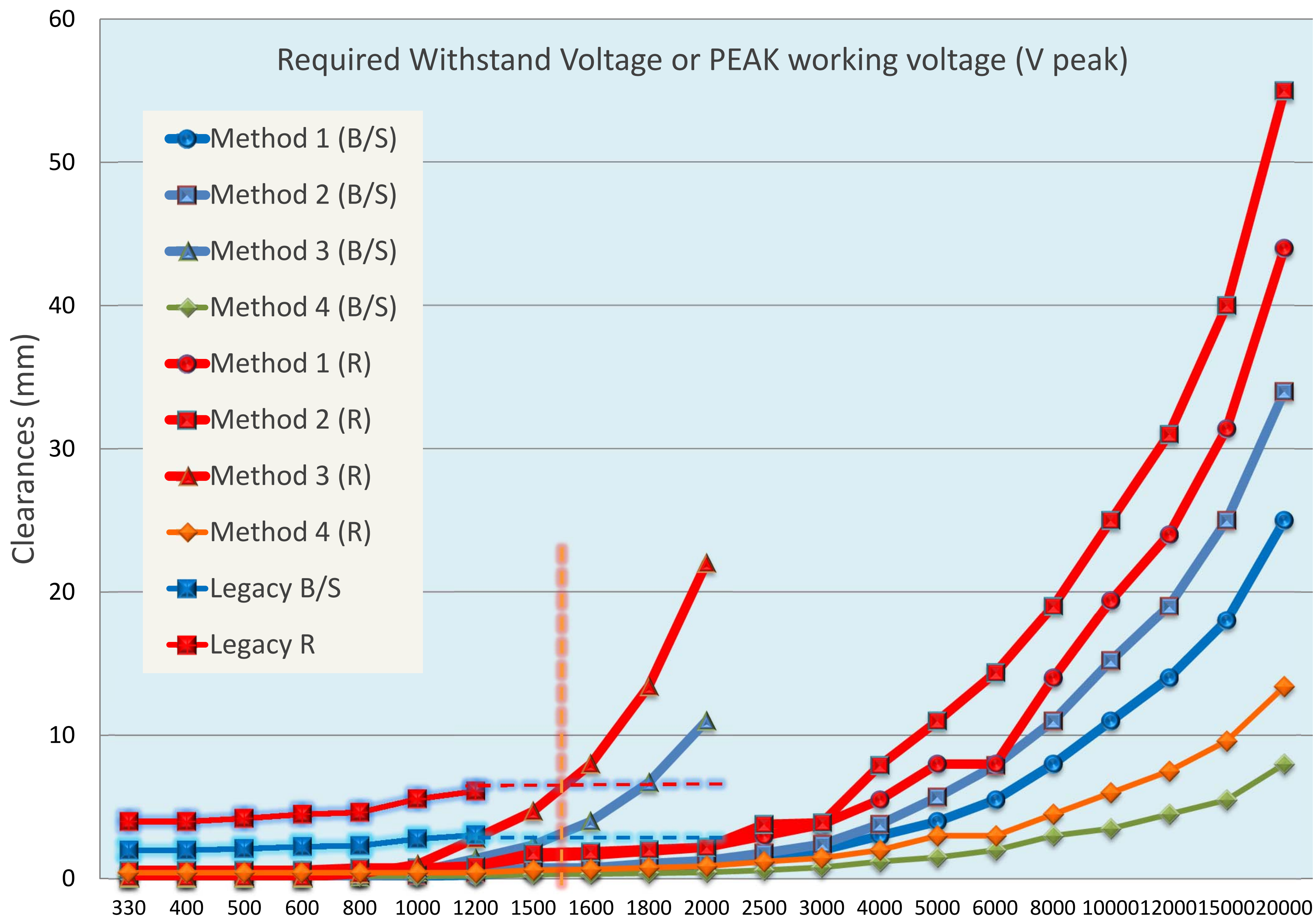
~80% retention rate

little effect on small clearances.



inhomogeneous field distribution

- the corona discharge phenomenon in **in**homogeneous fields (point-to-plane) is much more intense than homogeneous (plane-to-plane) that can be observed by naked eye.
- the worst-case U_b is about **50%** of that at power frequency.

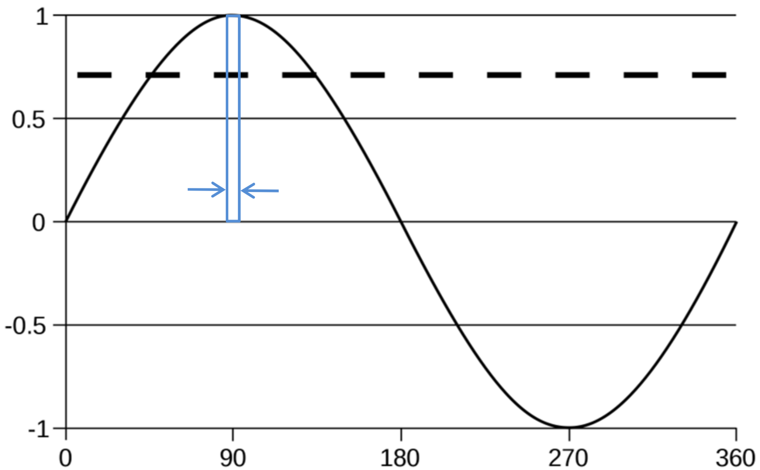


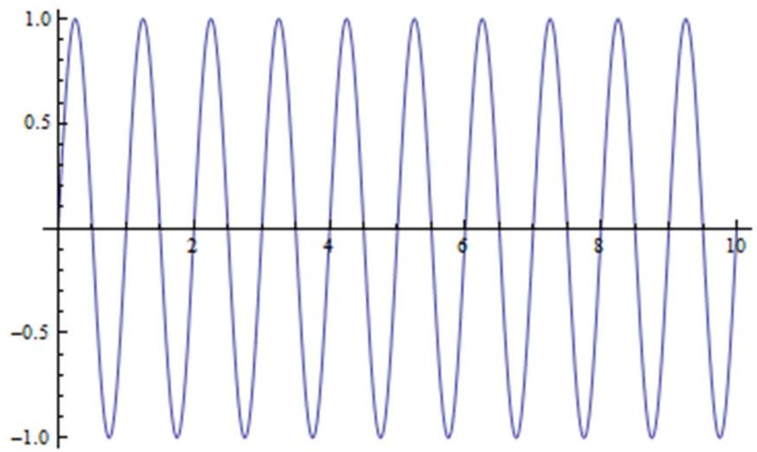
Required Withstand Voltage or PEAK working voltage (V peak)
Clearances (mm)
0
10
20
30
40
50
60
Method 1 (B/S)
Method 2 (B/S)
Method 3 (B/S)
Method 4 (B/S)
Method 1 (R)
Method 2 (R)
Method 3 (R)
Method 4 (R)
Legacy B/S
Legacy R
330
400
500
600
800
1000
1200
1500
1600
1800
2000
2500
3000
4000
5000
6000
8000
10000
12000
15000
20000

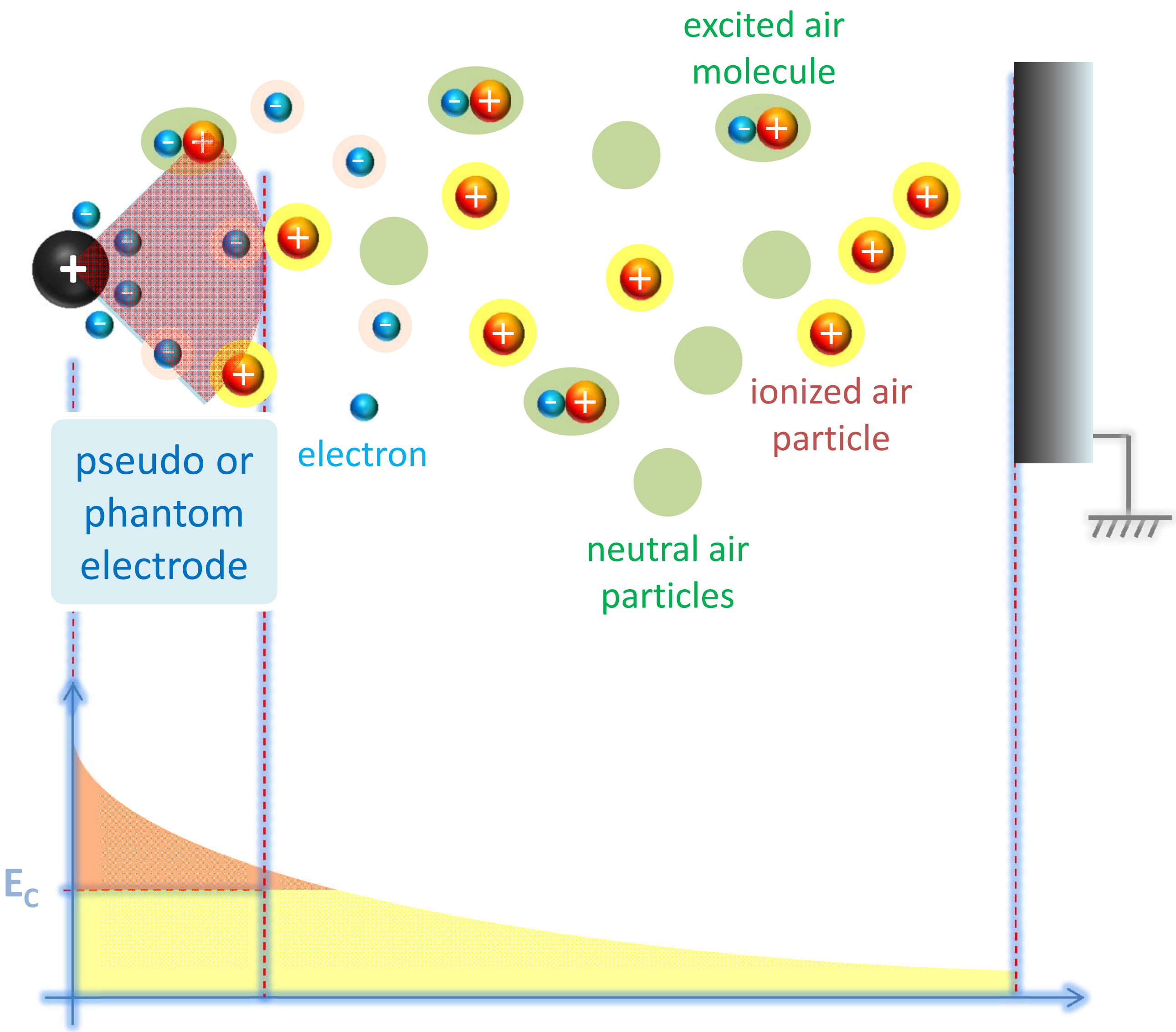
electrical breakdown in gases, i.e., clearances

typically takes more than 100 µs to develop.

- power frequency (10 ms):
  - a.c. (peak) and d.c. are virtually identical (98.77%).
- high frequencies (16.7 µs):
  - insufficient time to constitute complete breakdown.







if the clearances are large or at high frequencies, the ions might get trapped, resulting in the gradient distortion and consequent field strength weakening.

SOLID INSULATION

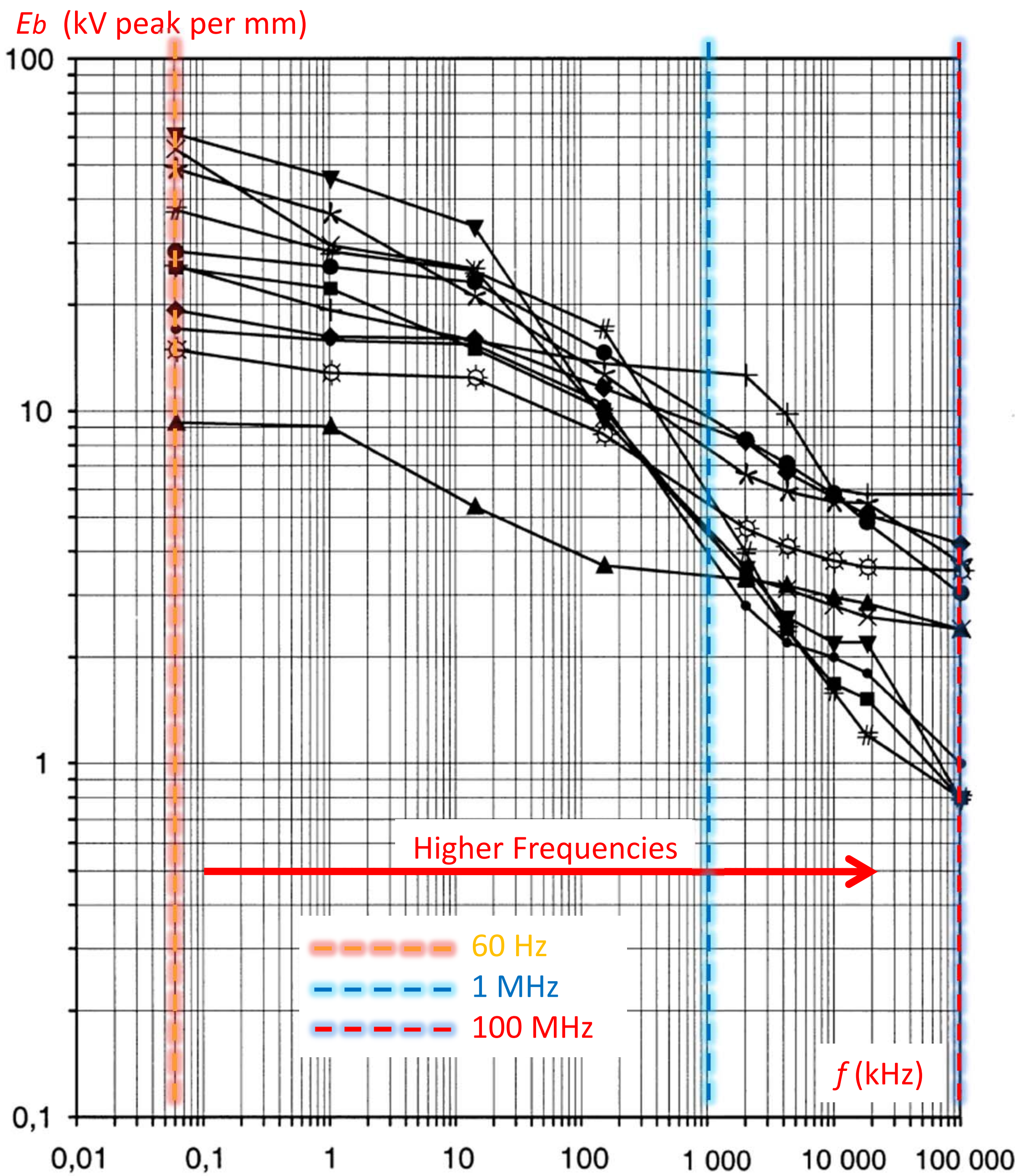
figure C.3 — breakdown at high frequency, solid insulation; d = 0.75 mm; comparison on short-time breakdown field strength E_b:

50/60 Hz = 1

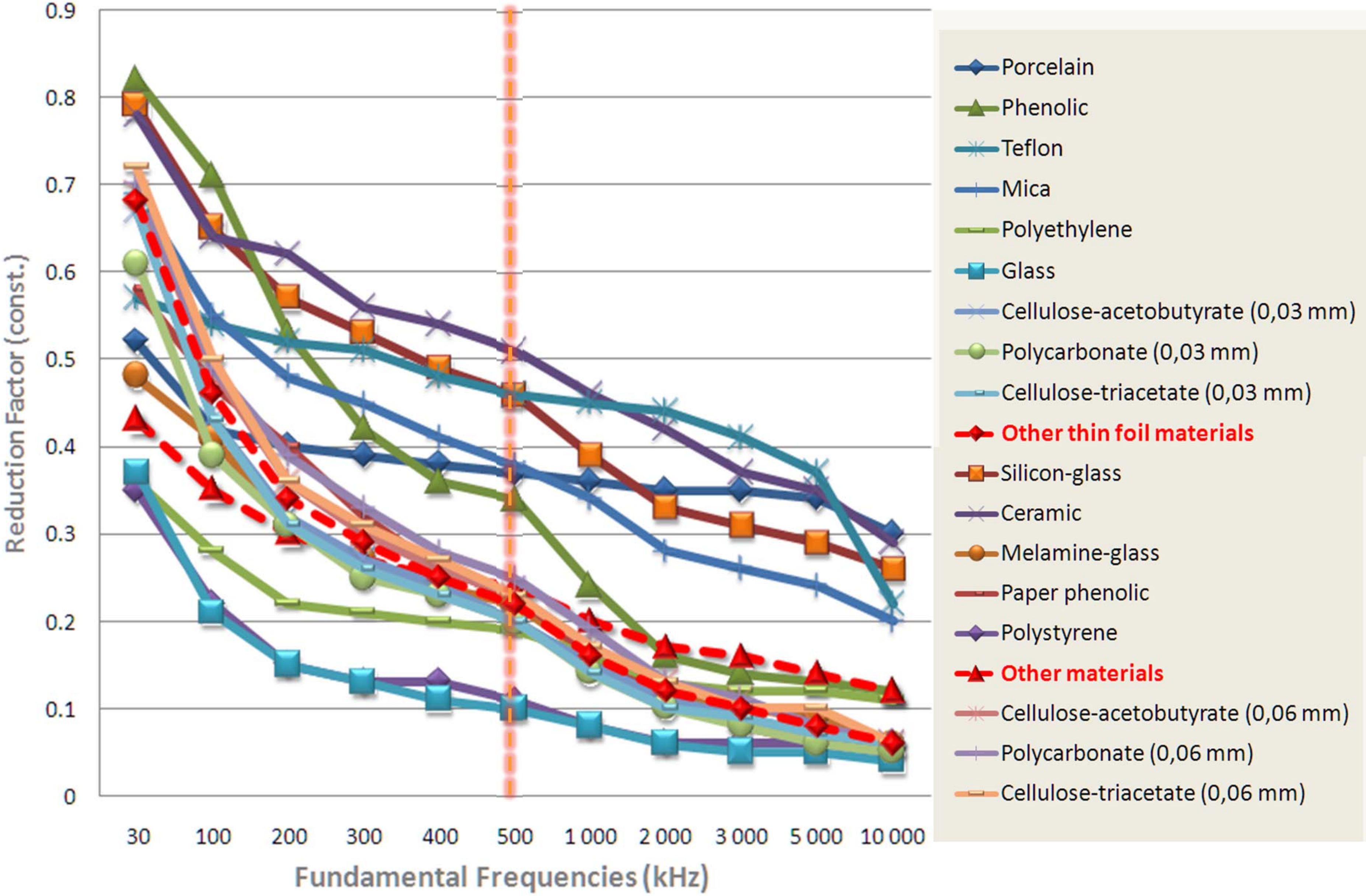
1 MHz = 0.66

100 MHz = 0.013

the bottom has not yet been reached!?



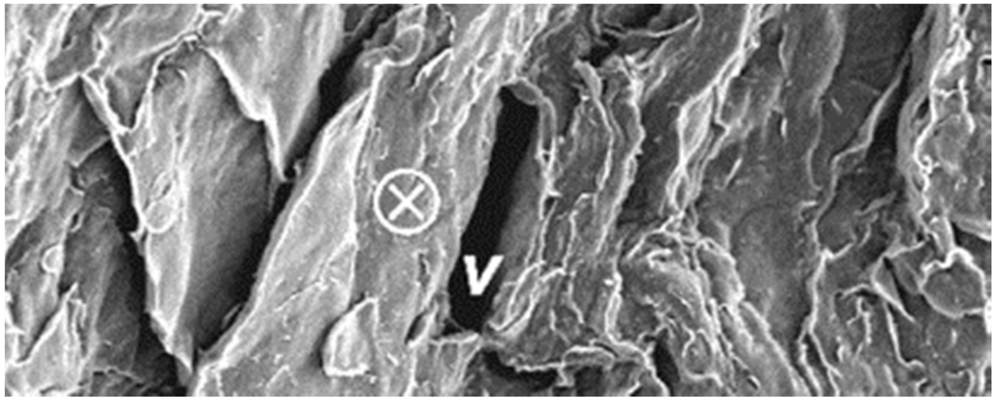
PHENOLIC
TEFLON
POLYETHYLENE
MICA
GLASS
SILICONE-GLASS
POLYSTYRENE
CERAMIC
PORCELAIN
MELAMINE-GLASS
PAPER-PHENOLIC

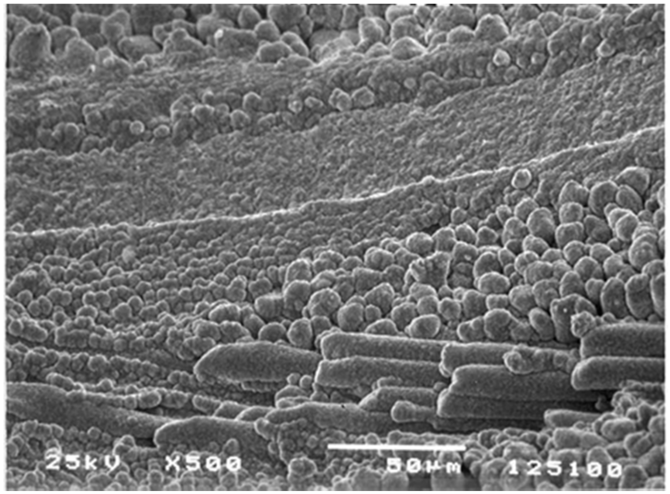


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Reduction Factor (const.)
30
100
200
300
400
500
1 000
2 000
3 000
5 000
10 000
Fundamental Frequencies (kHz)
Porcelain
Phenolic
Teflon
Mica
Polyethylene
Glass
Cellulose-acetobutyrate (0,03 mm)
Polycarbonate (0,03 mm)
Cellulose-triacetate (0,03 mm)
Other thin foil materials
Silicon-glass
Ceramic
Melamine-glass
Paper phenolic
Polystyrene
Other materials
Cellulose-acetobutyrate (0,06 mm)
Polycarbonate (0,06 mm)
Cellulose-triacetate (0,06 mm)

solid insulation

- compared to air insulation, solid insulation provides at least a **ten-fold** increase in electric strength.
- however, in practice, a PD can occur in embedded voids or air gaps in solid dielectrics at a PD-inception voltage far below its breakdown voltage, reducing its voltage withstand ability, and likely resulting in the complete destruction of most solid dielectrics.





modeling a gas-filled void

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d}$$

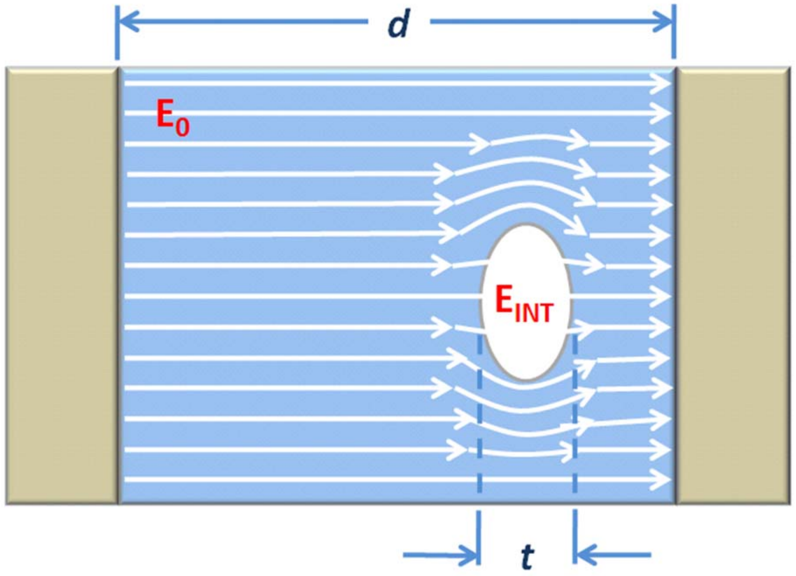
- ε_r (air) = **1.0006**;
- ε_r (PC, polycarbonate) = **2.3**;
- ε_r (FR-4) = **4.4**;

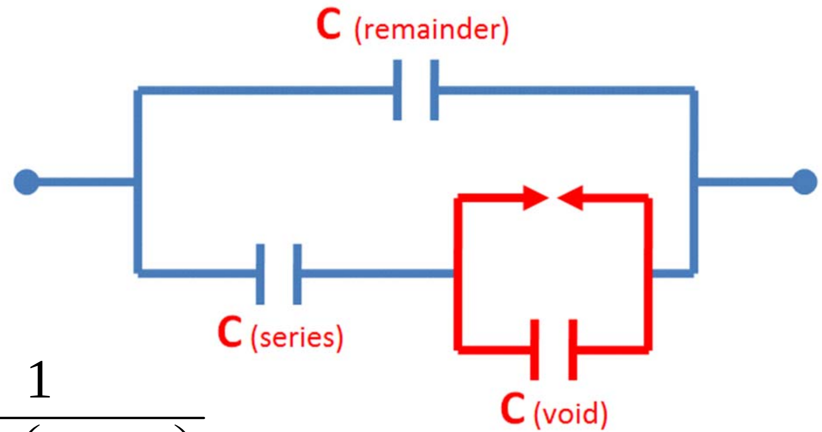
$C_{(remainder)} \gg C_{(void)}$

$C_{(void)} \gg C_{(series)}$

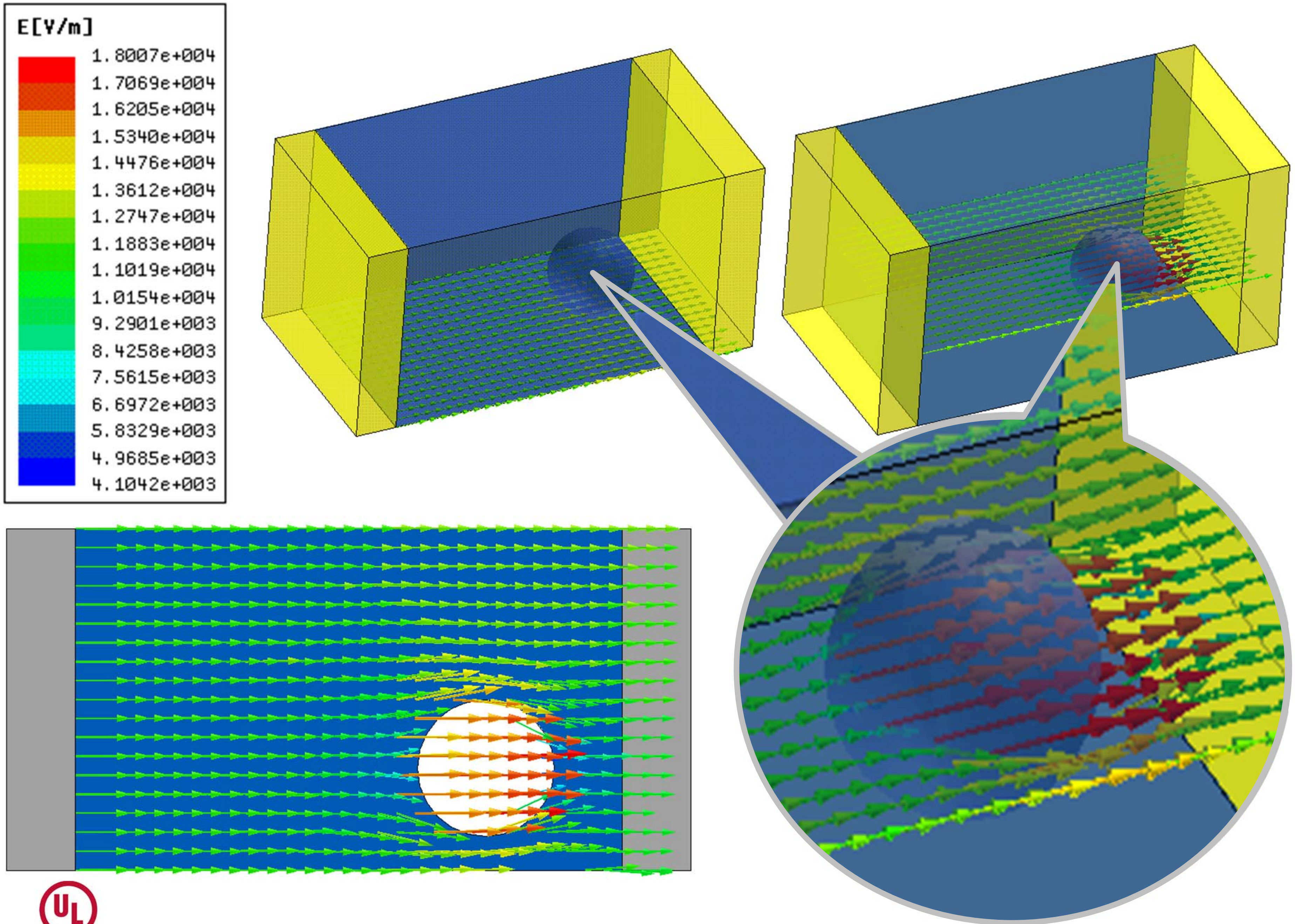
for any dielectric of the same size:

$V_{(void)} = \varepsilon_r * V_{(dielectric)}$



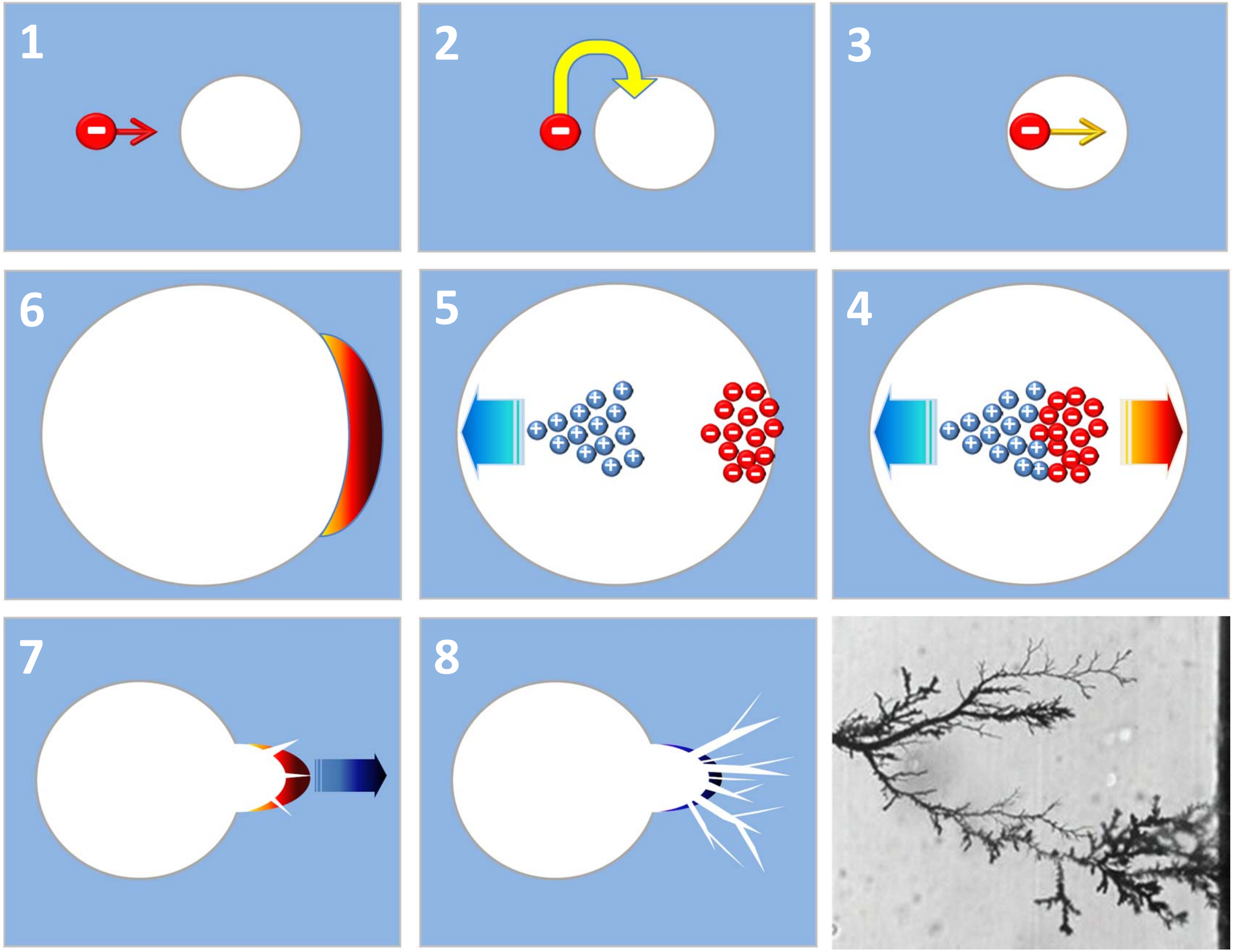


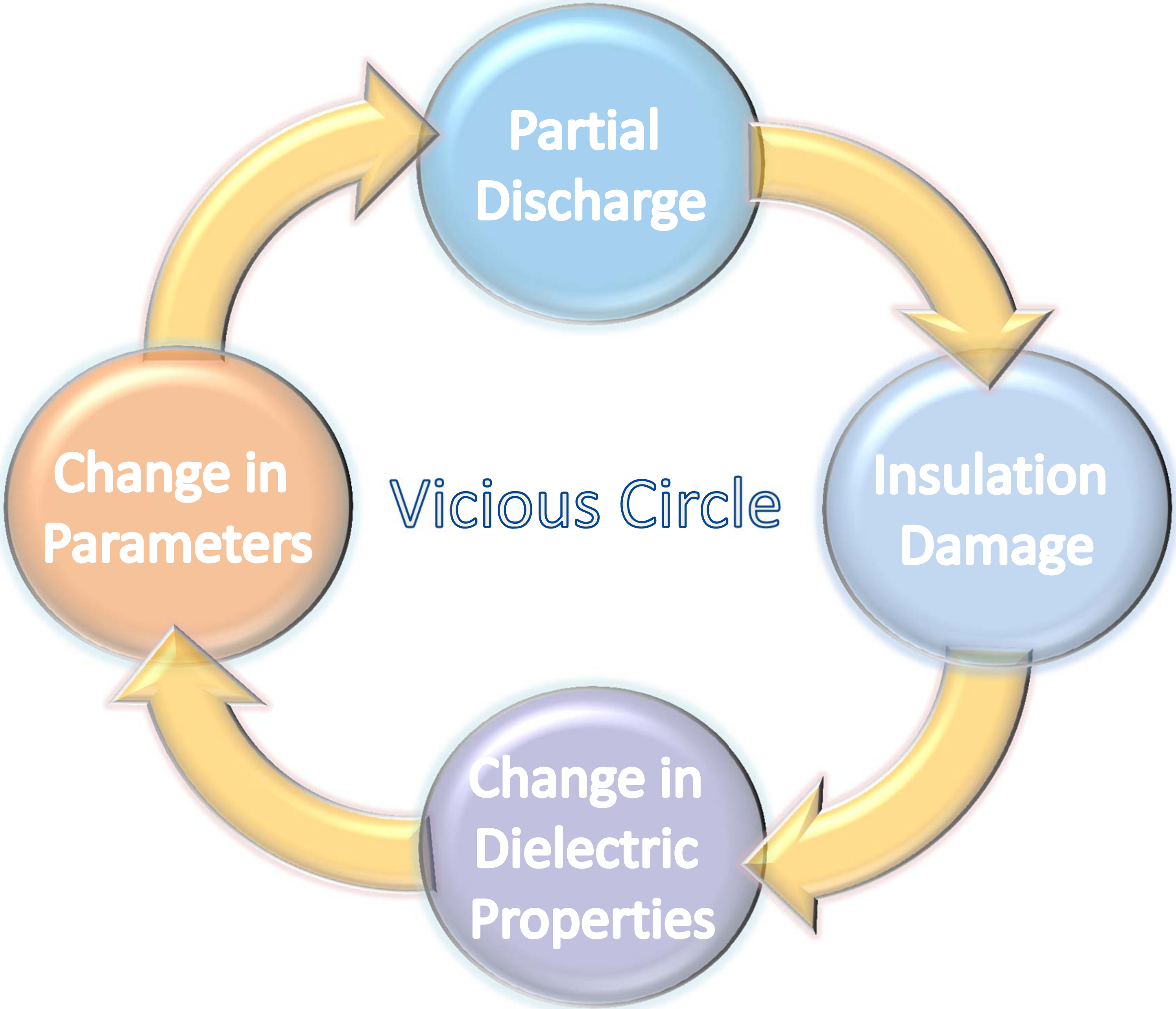
$$V_{(void)} = V \frac{C_{(series)}}{C_{(series)} + C_{(void)}} = V \frac{1}{1 + \frac{1}{\varepsilon_r}\left(\frac{d}{t} - 1\right)}$$



E[V/m]
1.8007e+004
1.7069e+004
1.6205e+004
1.5340e+004
1.4476e+004
1.3612e+004
1.2747e+004
1.1883e+004
1.1019e+004
1.0154e+004
9.2901e+003
8.4258e+003
7.5615e+003
6.6972e+003
5.8329e+003
4.9685e+003
4.1042e+003

void-to-tree transition




Partial Discharge
Insulation Damage
Change in Dielectric Properties
Change in Parameters
Vicious Circle

CREEPAGE DISTANCES

the experiment

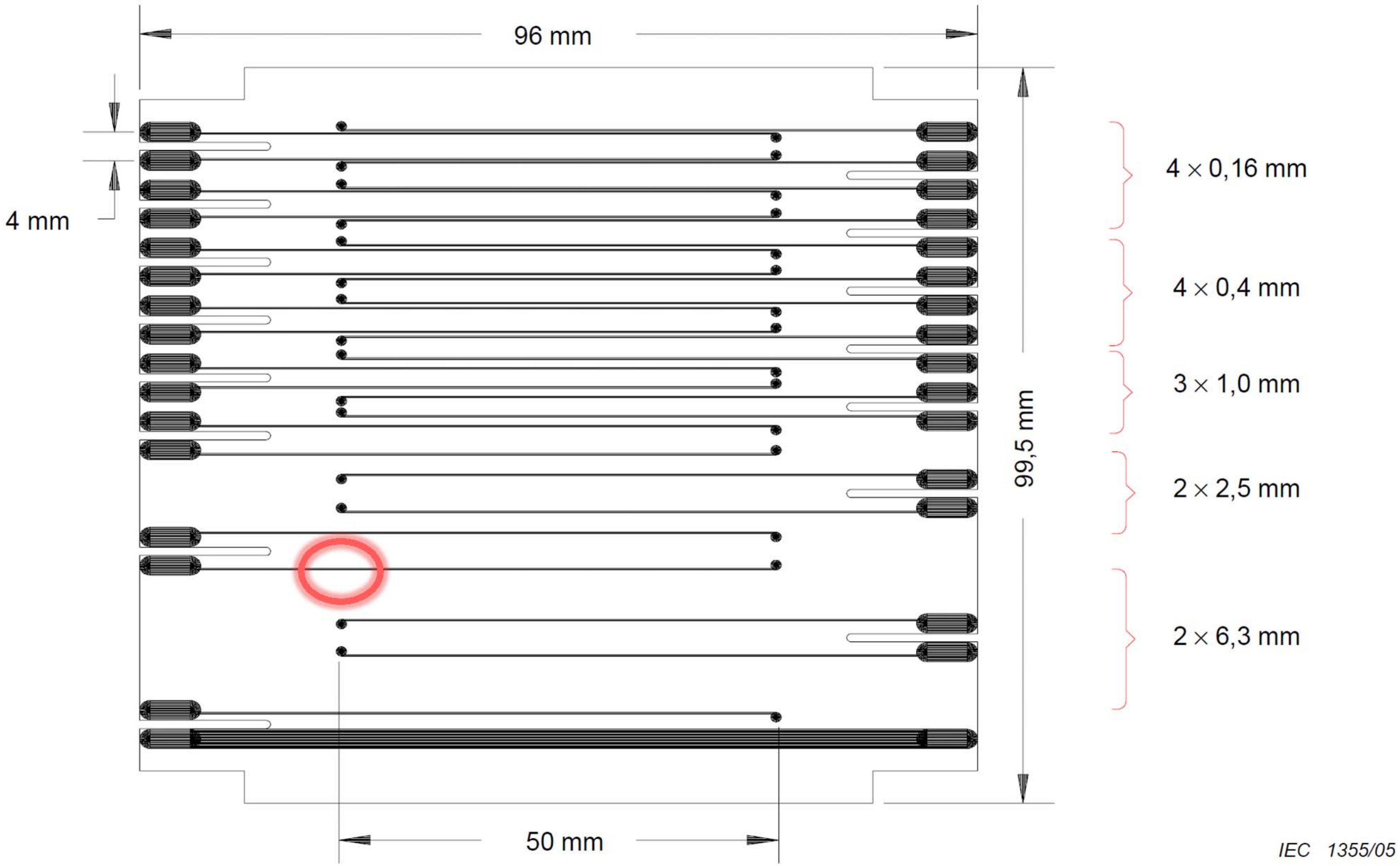


Figure B.3 — Breakdown Voltage (U_b)

U_b is less relevant to frequency factor

larger creepage distances do not add to the breakdown voltage, U_b

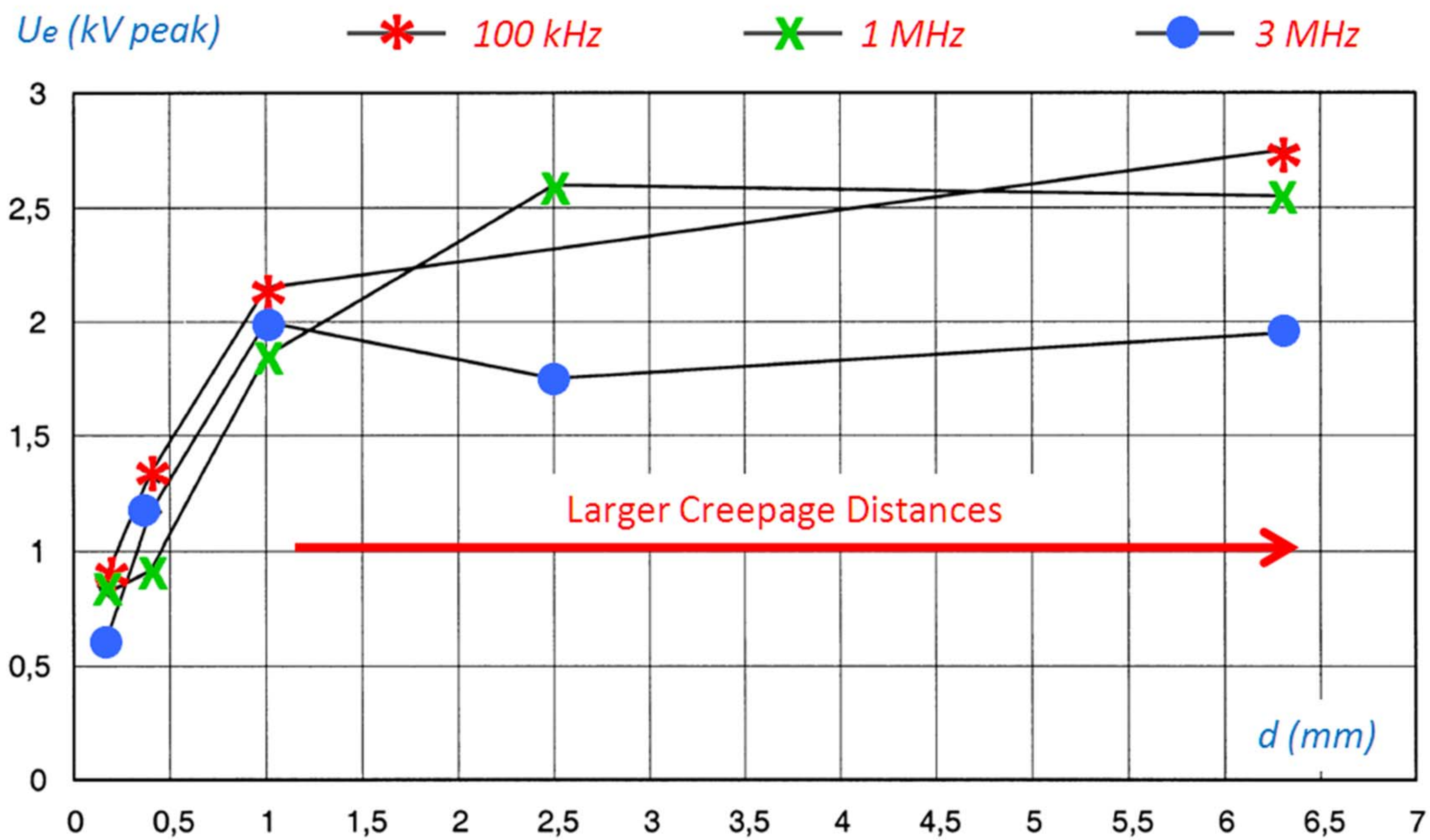
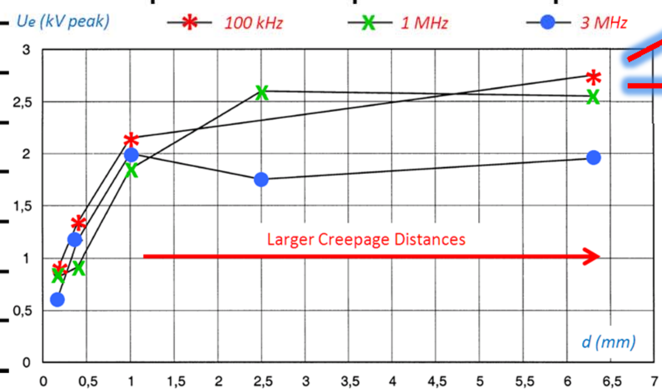
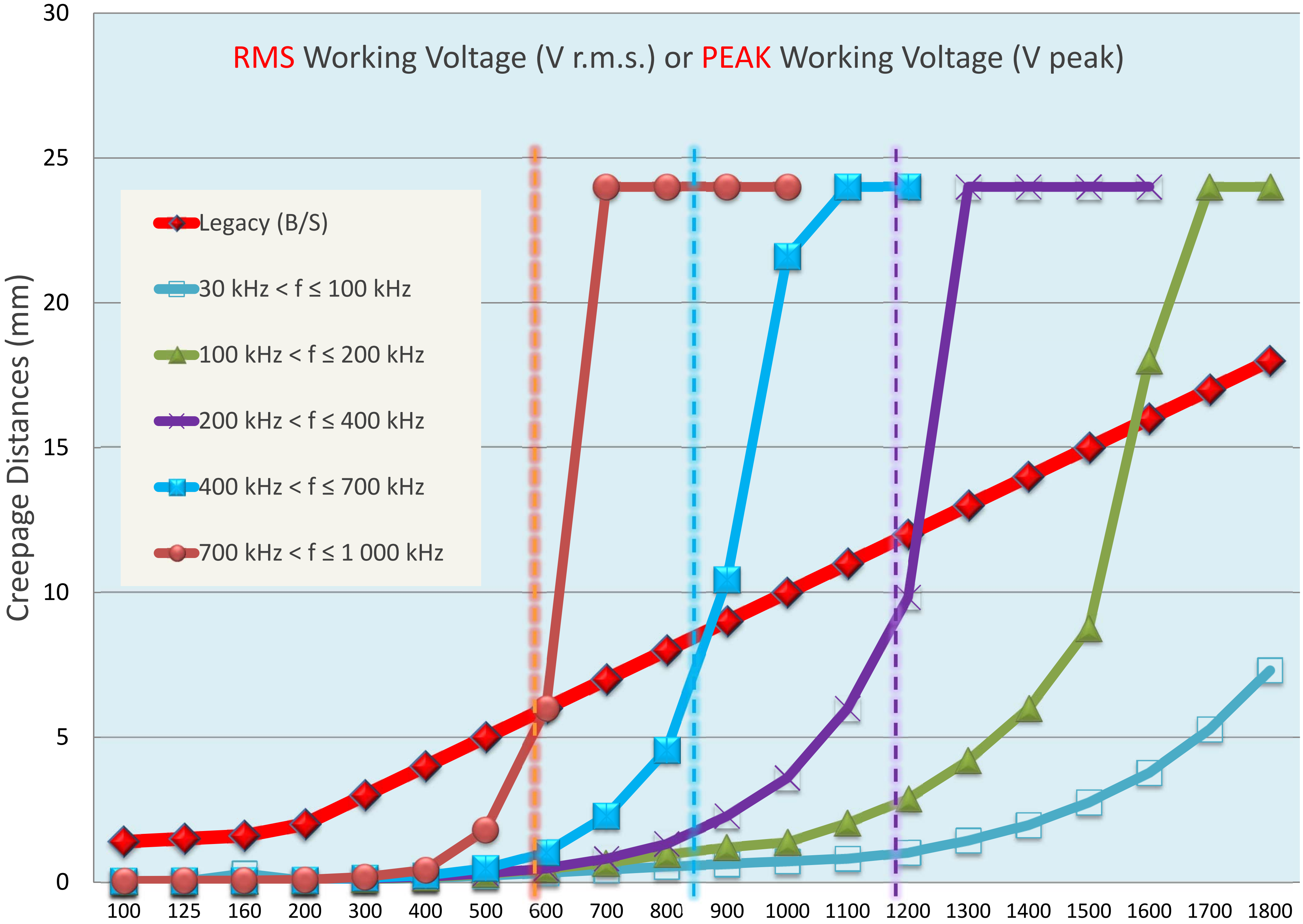


Table 2 – Minimum values of creepage distances for different frequency ranges

Voltage	Creepage distance a) mm						
U_{peak} kV	for 30 kHz < f ≤ 100 kHz	for f ≤ 0,2 MHz b)	for f ≤ 0,4 MHz b)	for f ≤ 0,7 MHz b)	for f ≤ 1 MHz b)	for f ≤ 2 MHz b)	for f ≤ 3 MHz b)
0,1	0,0167						0,3
0,2	0,042					0,15	2,8
0,3	0,083	0,09	0,09	0,09	0,09	0,8	20
0,4	0,125	0,13	0,15	0,19	0,35	4,5	
0,5	0,183	0,19	0,25	0,4	1,5	20	
0,6	0,267	0,27	0,4	0,85	5		
0,7	0,358	0,38	0,68	1,9	20		
0,8	0,45	0,55	1,1	3,8			
0,9	0,525	0,82	1,9	8,7			
1	0,6	1,15	3	18			
1,1	0,683	1,7	5				
1,2	0,85	2,4	8,2				
1,3	1,2	3,5					
1,4	1,65	5					
1,5	2,3	7,3					
1,6	3,15						
1,7	4,4						
1,8	6,1						



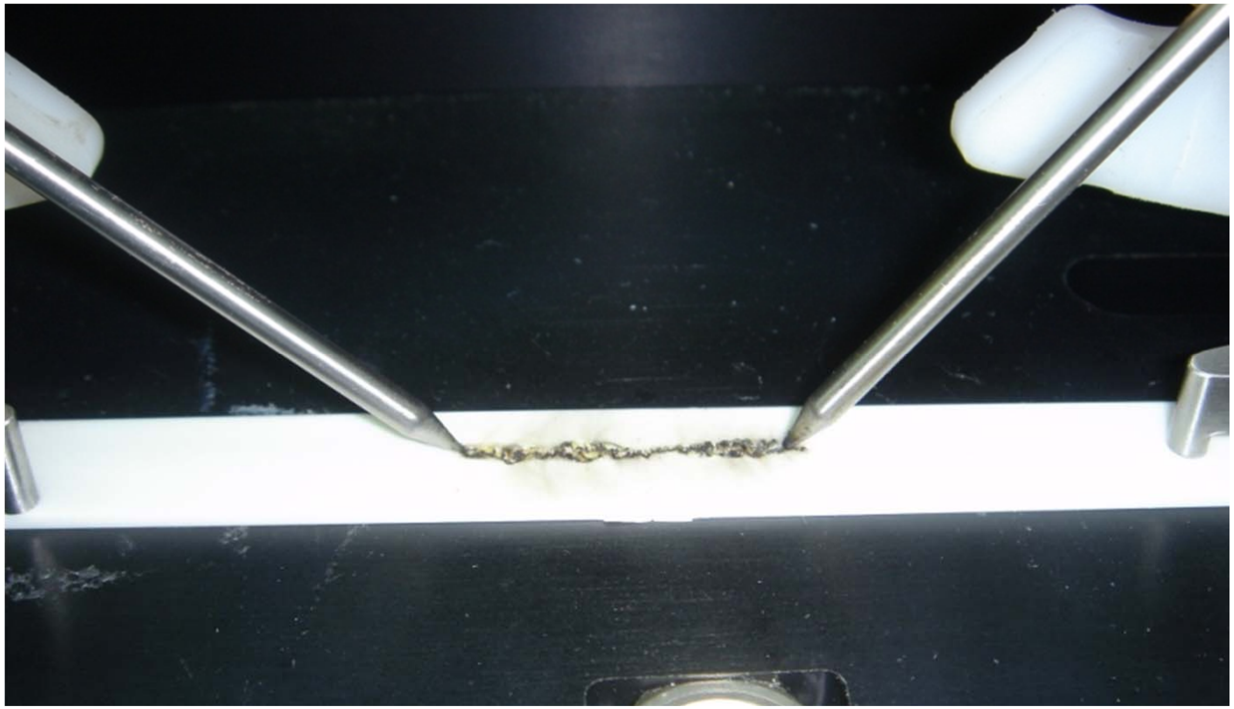


RMS Working Voltage (V r.m.s.) or PEAK Working Voltage (V peak)
Creepage Distances (mm)
Legacy (B/S)
30 kHz < f ≤ 100 kHz
100 kHz < f ≤ 200 kHz
200 kHz < f ≤ 400 kHz
400 kHz < f ≤ 700 kHz
700 kHz < f ≤ 1 000 kHz
0
5
10
15
20
25
30
100
125
160
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800

surface breakdown, i.e., creepage distances

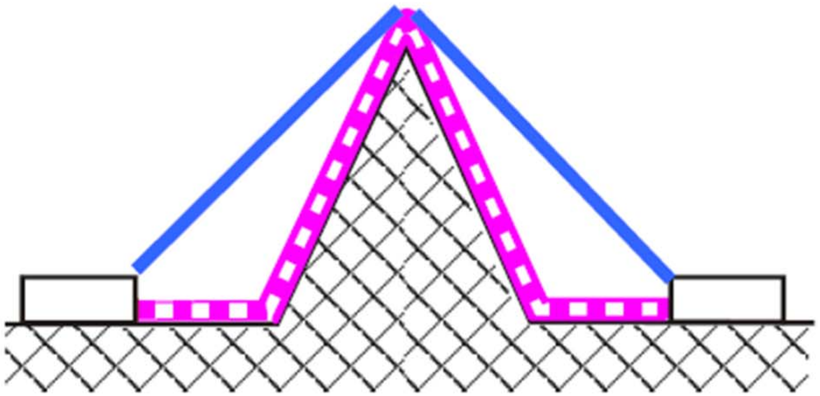
unlike clearances, creepage distances and solid insulation are **NOT** replenishable — permanent damage such as puncture or carbonized tracking, is likely.

- in this sense, clearances are less vulnerable to PD.

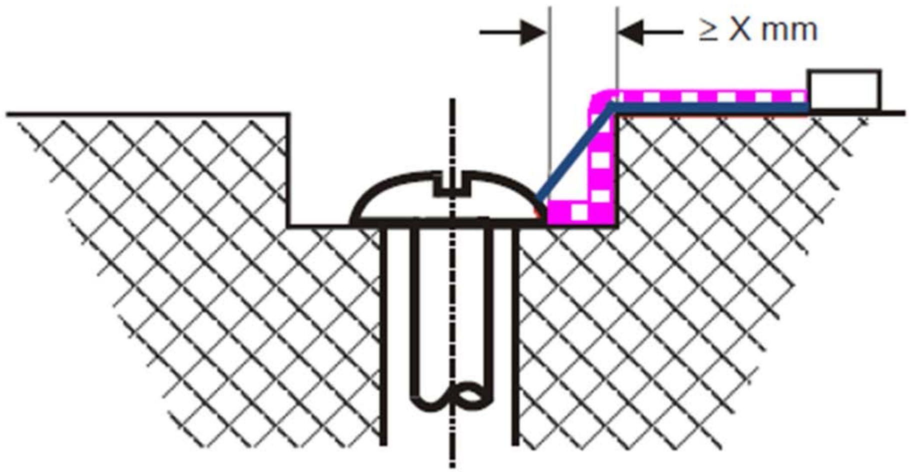


please humor me while I speculate…

what does it mean by saying **"creepage distances must be equal to or greater than clearances?"**

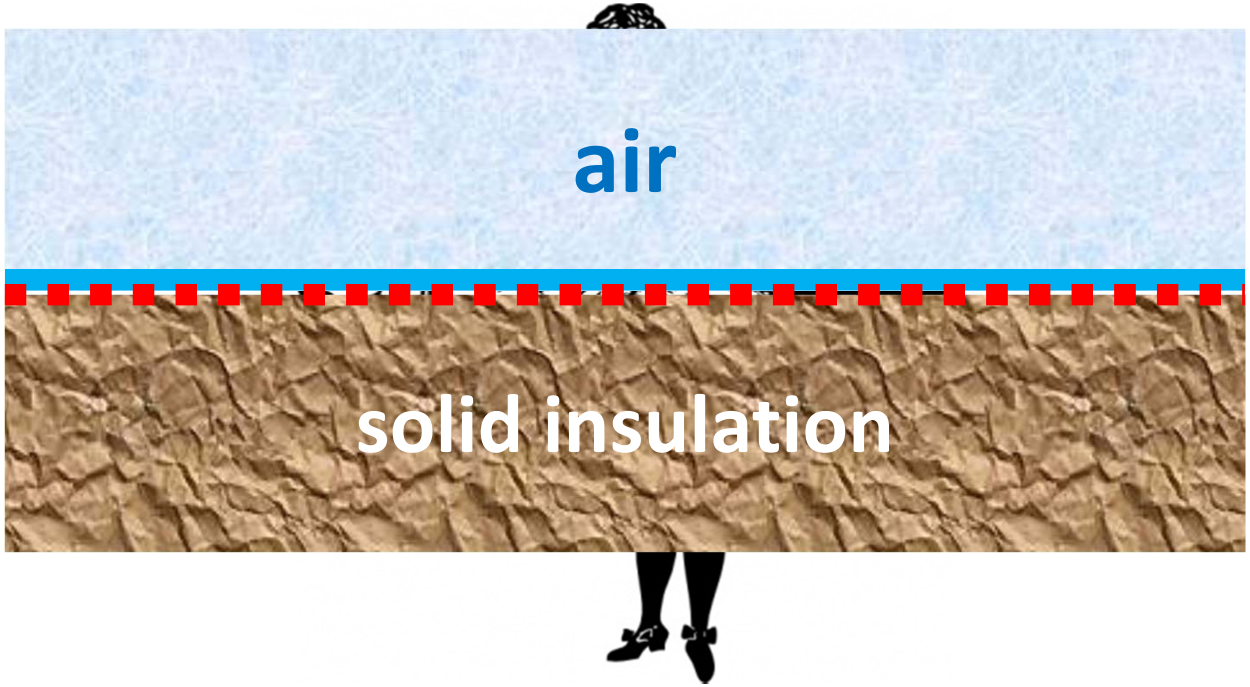


geometry?

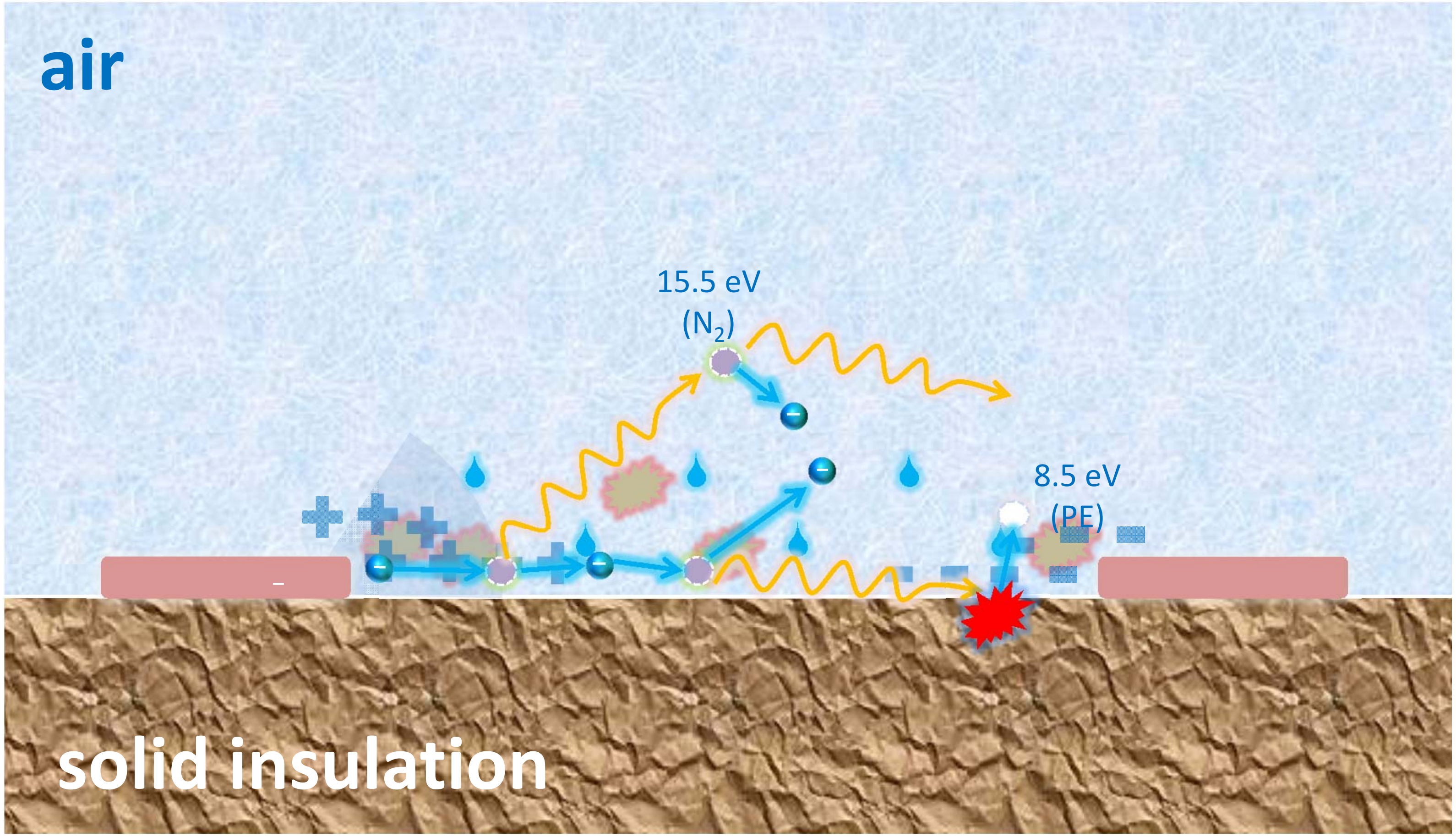


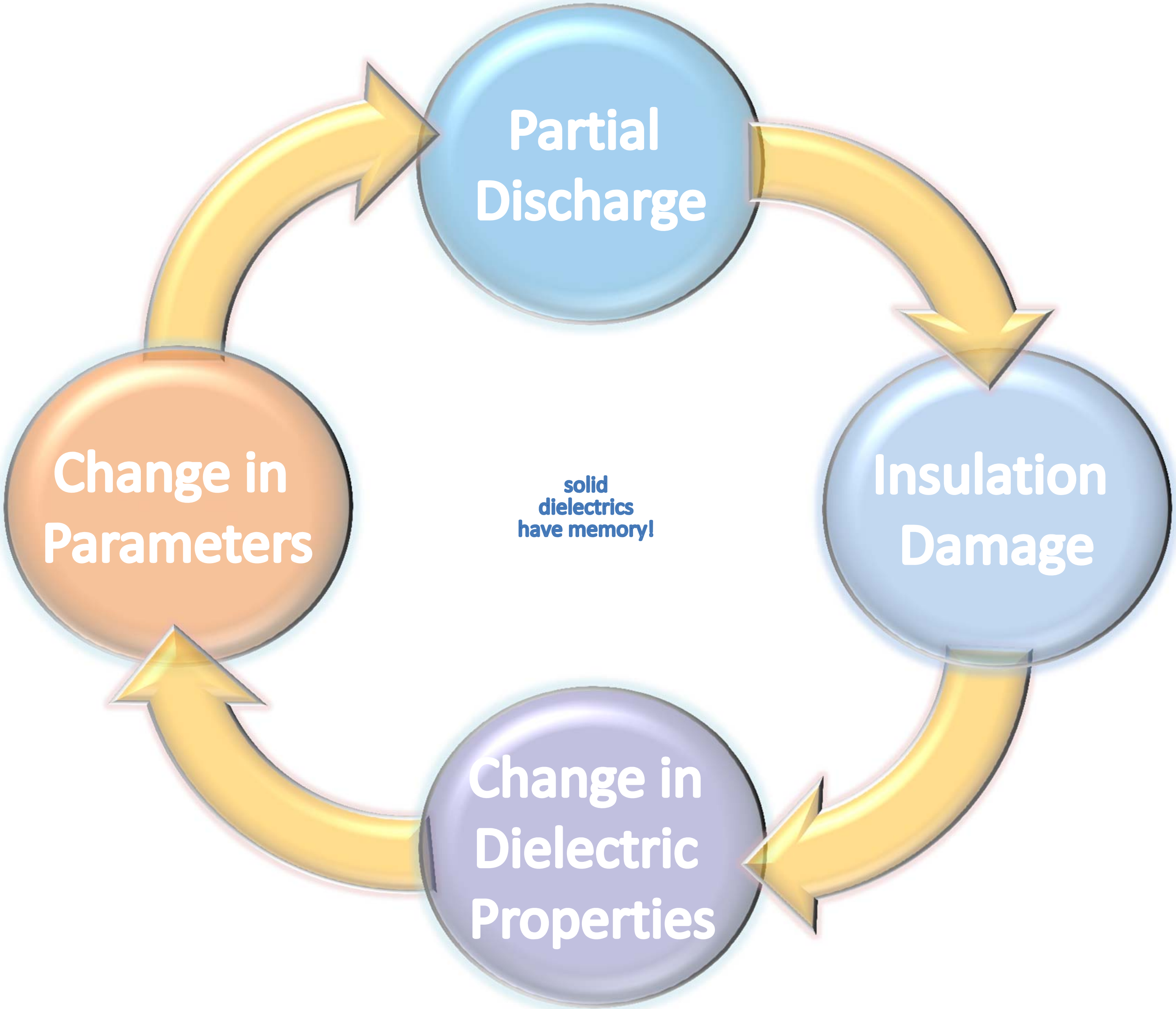
**however,
from this aspect it is difficult to understand
what is the relationship between CL and CR.**

I would say when we're talking about the **creepage distances** we have to keep in mind that we re talking about **clearances** as well.



how creepage distances and clearances interact with each other?




Partial Discharge
Insulation Damage
Change in Dielectric Properties
Change in Parameters
solid dielectrics have memory!

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謝謝大家的時間！