Testing / Specifications and Long-term Performance of Electrical Systems

R

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  - **Stress grading design**
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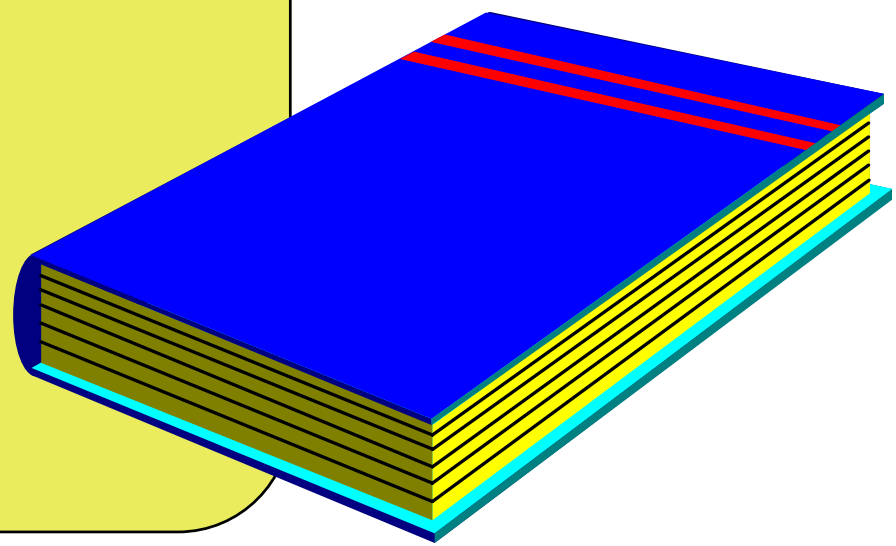
- **Summary**



Requirements

- **Expected life-time > 30 Years**
- **Must meet relevant standards**
  - **CENELEC HD 629.1; HD 628.1**
  - **IEC 502 part 4**
  - **IEEE 404**
  - **IEEE 48**
- **Easy reproducible field installation**

General Design Parameter Termination

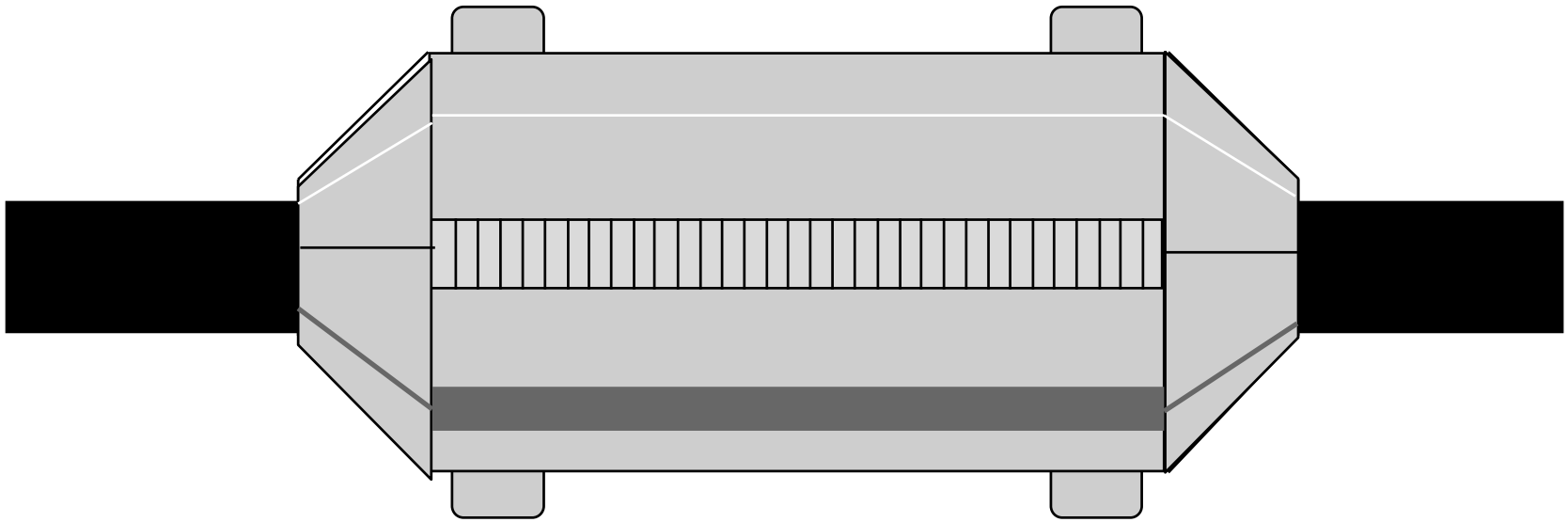
- **Termination lug**
  - Lug to meet relevant specification, i.e. IEC 1238, ANSI 119.4
- **Stress grading**
  - axial and radial stress
    - £max. E-stress of the cable
    - £break-down stress in air
- **Flash distance**
  - in accordance with national / international standards i.e. IEC 71-x

- **Creepage distance**
  - in accordance to pollution levels defined in guide IEC 815
- **Environment**
  - Track & erosion resistant material i. e. ASTM D2703
  - Low leakage current under humidity

General Design Parameter Joints

- **Conductor connection**
  - Connector to meet relevant standards i.e. IEC 1238, ANSI 119.4
- **Stress grading**
  - axial and radial interface stress
    - £ max. E-stress of the cable
- **Insulation wall thickness**
  - W_{ins} ³ 1.25 x cable insulation wall thickness
- **Joint Shield**
  - Conductivity / Stability equal or better than cable semicon
- **Shield continuity**
  - Must meet earth fault and short circuit performance of cable design (eventually reduction to network conditions)
- **Oversheath**
  - Equivalent to applied wall thickness of cable oversheath (min. 2.5mm)
- **Sealant Overlap**
  - L_s ³ 2.5 x cable OD

Joint Design



Conductor Profiles

- **Conductor**
  - ✓ **Al /CU**
    - u **Shape**
      - **sector**
      - **round**
  - ✓ **Design**
    - **stranded**
    - **solid**

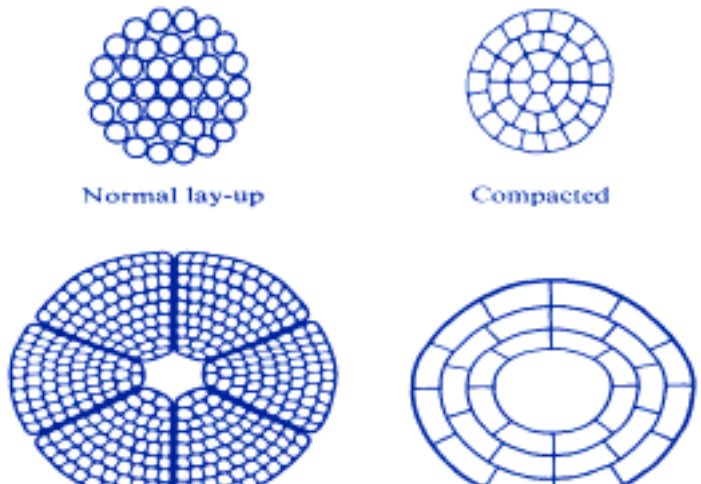


Fig. 1.4
Construction of multi-core circular conductors

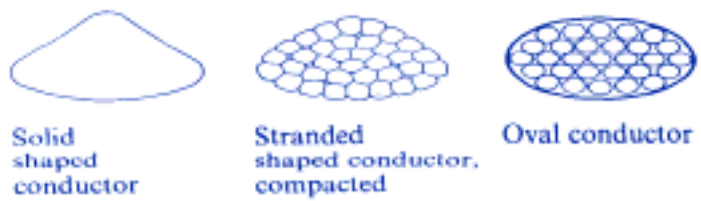


Fig. 1.5
Construction of sector shaped conductors

Connector Standard

- **Example:** Scope of IEC 1238
  - When a design, which meets the requirements of IEC 1238 standard, then it is expected, that
    - a.) " the resistance of the connection will remain stable "
    - b.)" the temperature of the connector will be of the same order or less than that of the conductor "
    - c.) " application of short circuit currents will not affect a.) , b.) or d.)"
    - d.) " the mechanical strength will be fit for the purpose "

Product Design Requirements

The first estimation is determined to:

$$E_d = k_t\, k_m\, k_h\, k_v\, E_{op}$$

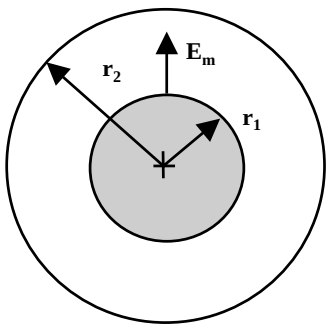
k= ageing factors

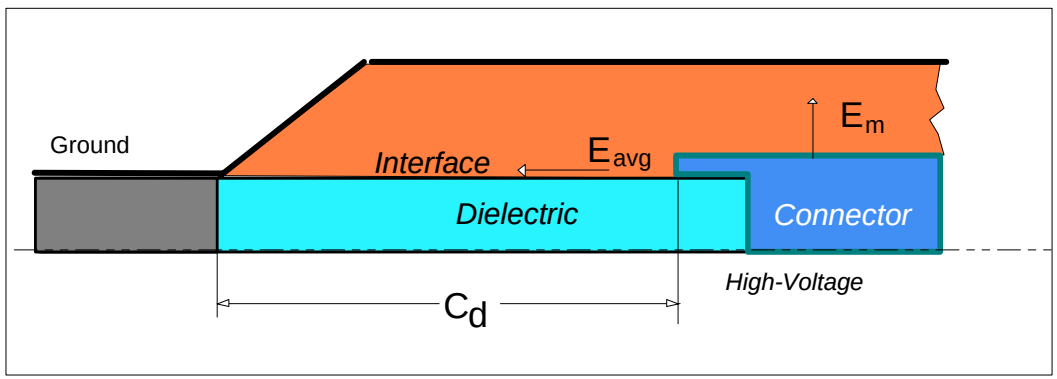
- ***Temperature***
- ***Mechanical Stress***
- ***Humidity***
- ***Volume***

E_{op} = Operation Stress

Stress Grading

- The design is based on the following electrical parameters
  - Maximal radial stress
  - Maximal interface stress



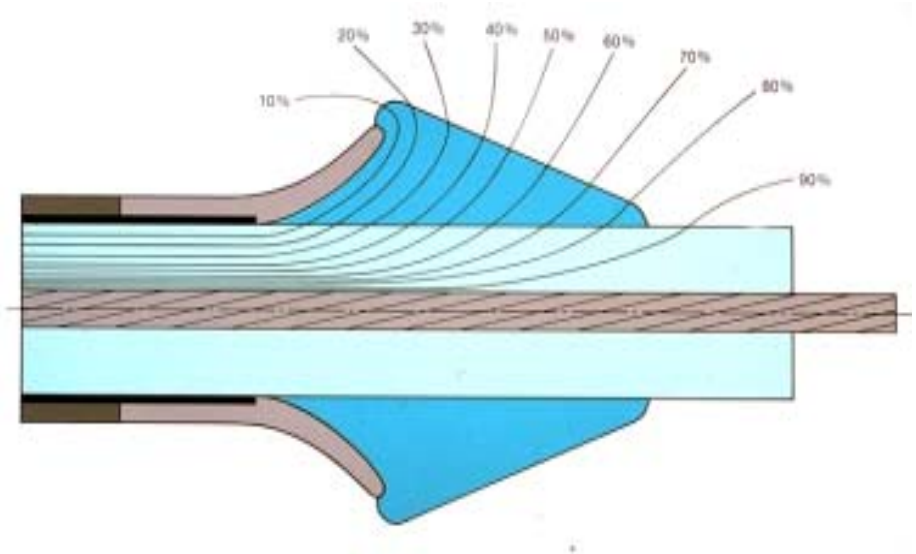


$$E = \frac{V}{r \cdot \ln(r_o / r_i)}$$

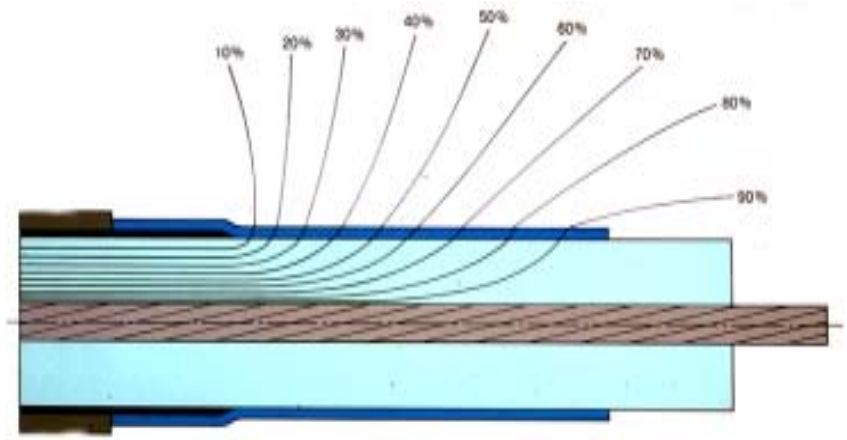
$$E_{avg} = \mathrm{BIL} / C_d \qquad (2)$$

Methods of Stress Grading

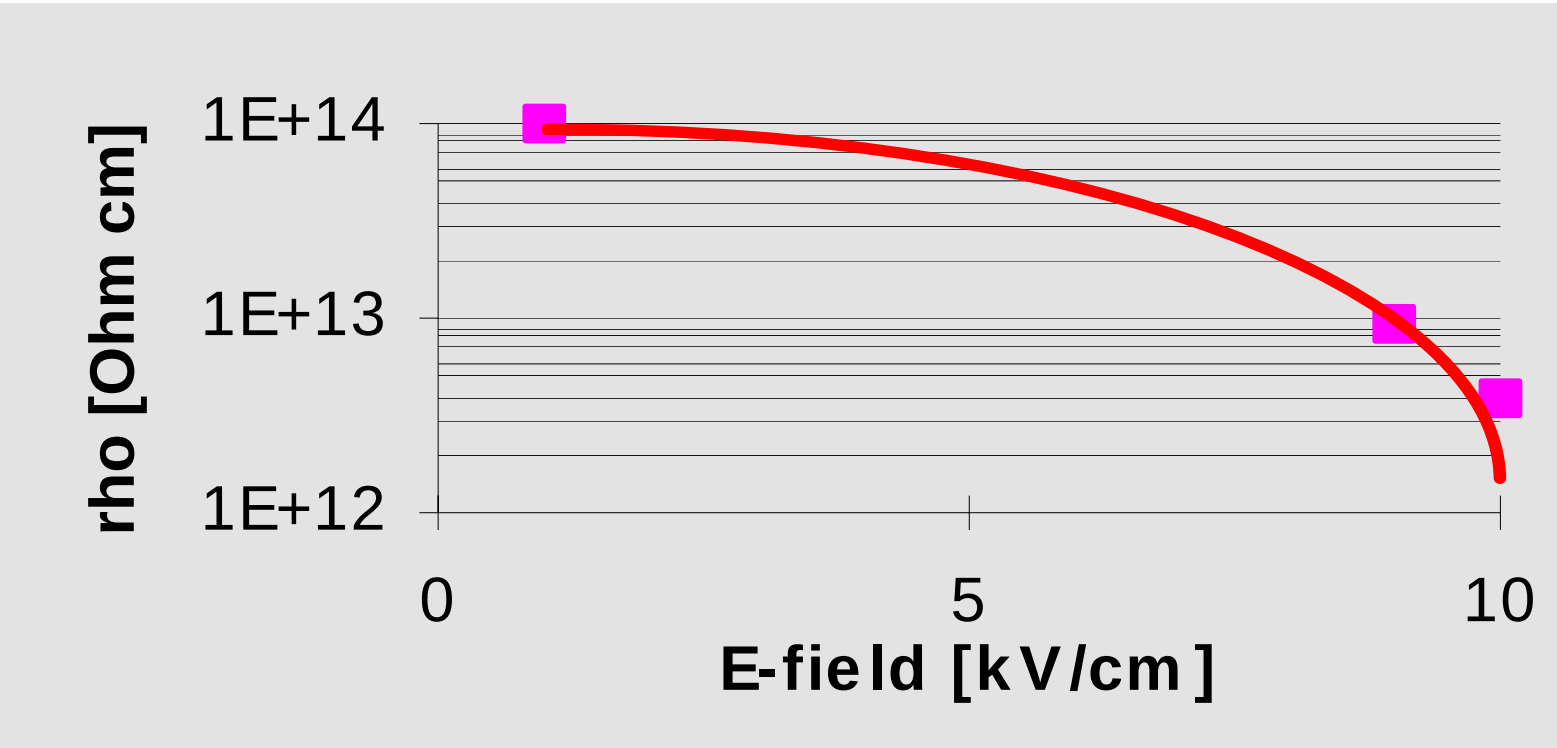
F by Geometry



F by Material Technology



Vol. Res. versus E-field



- The material technology provides non linear electrical stress management
- **The specific resistance is E-field dependant**

E-Field-Vector measured on Termination

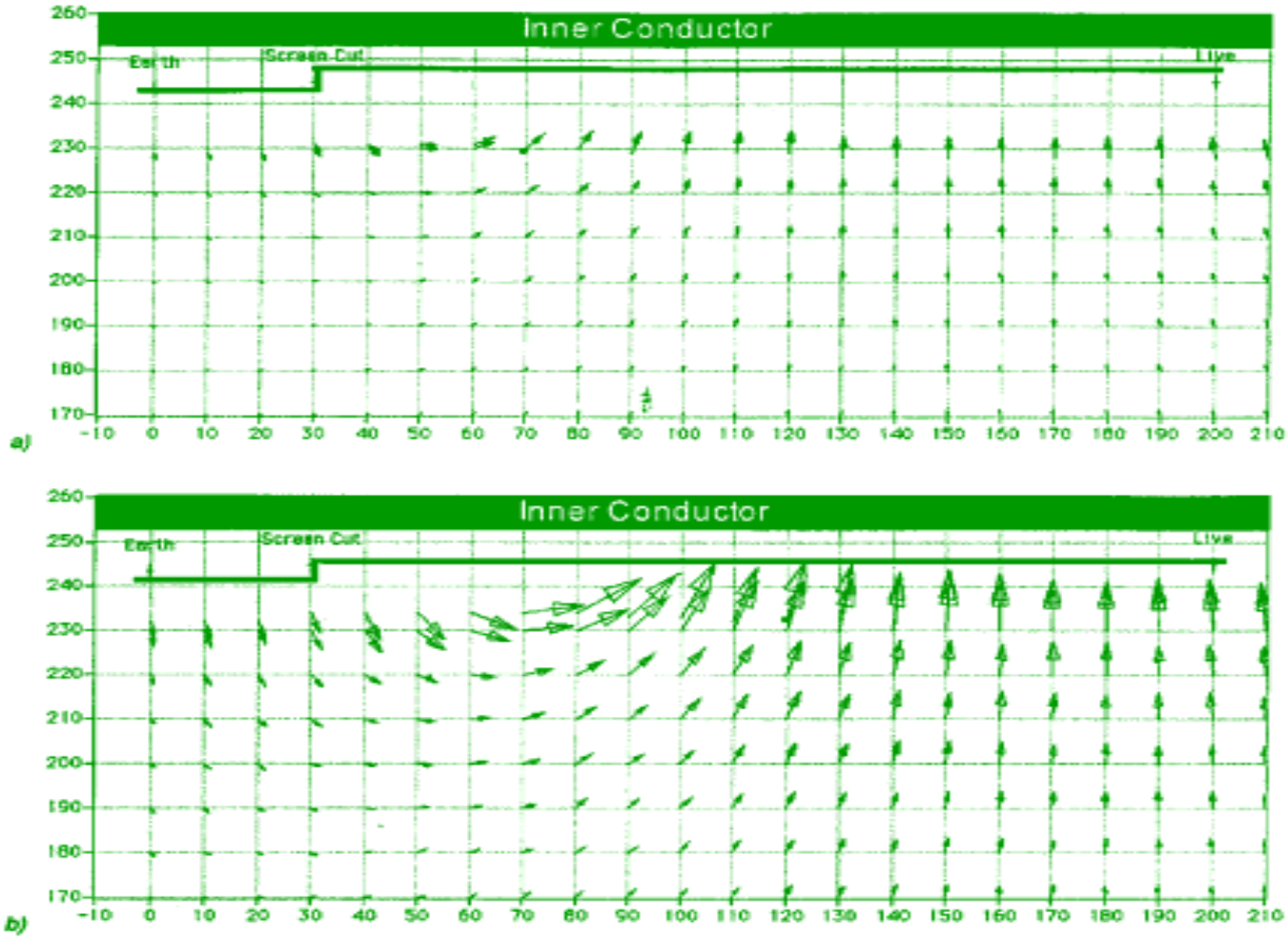
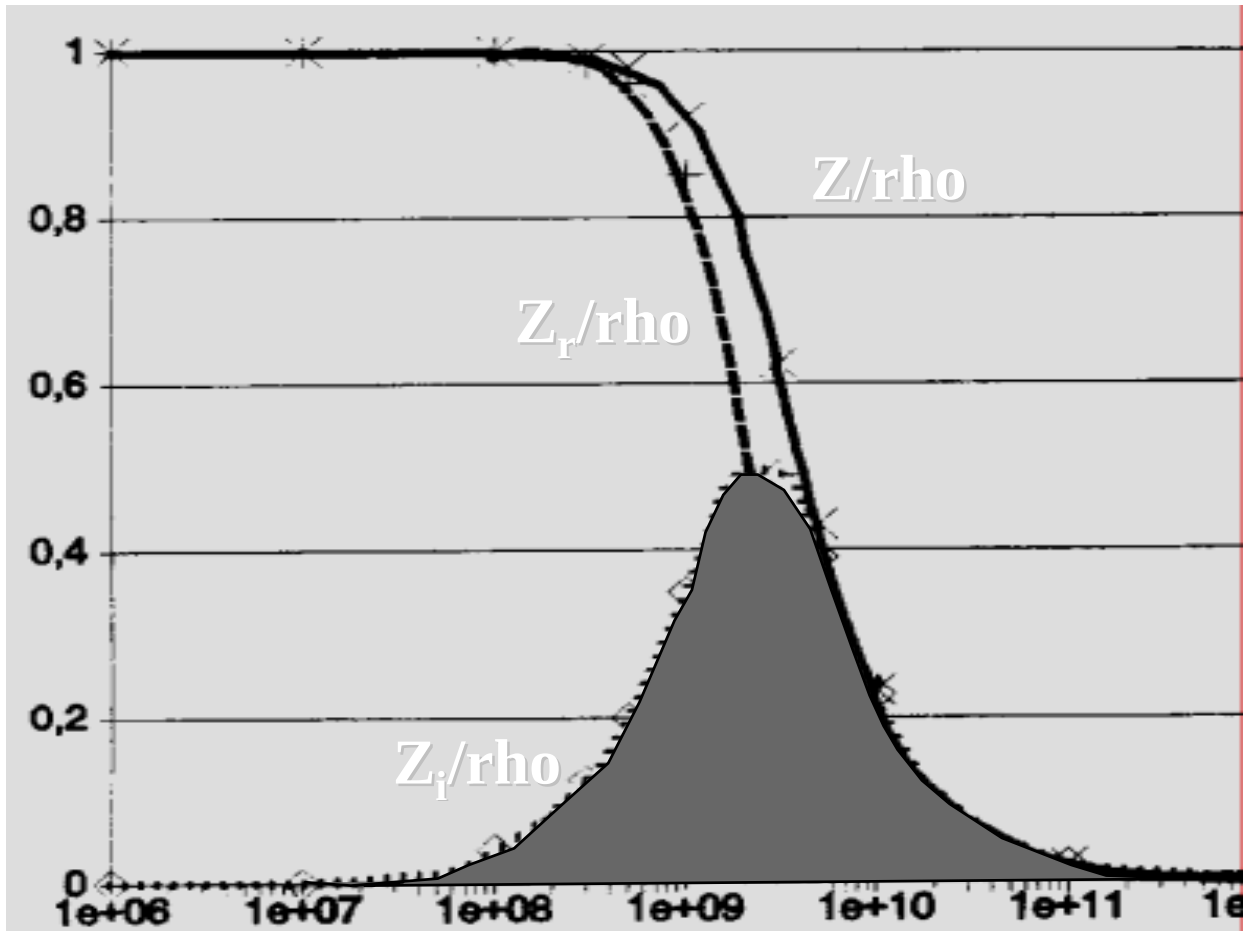
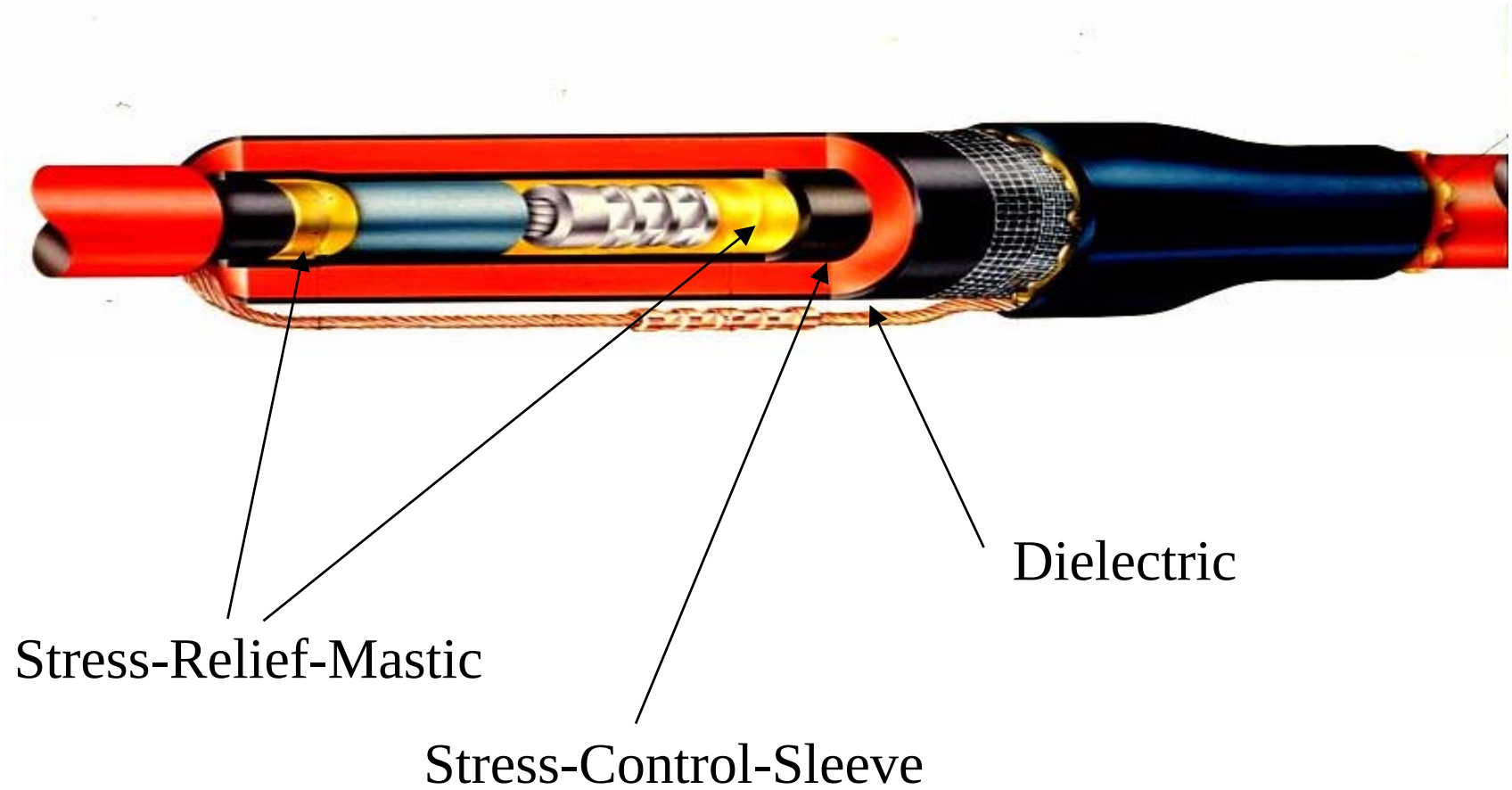


Fig. 4: Cable Termination with semiconductive stress control layer at a) 5 kV and b) 30 kV

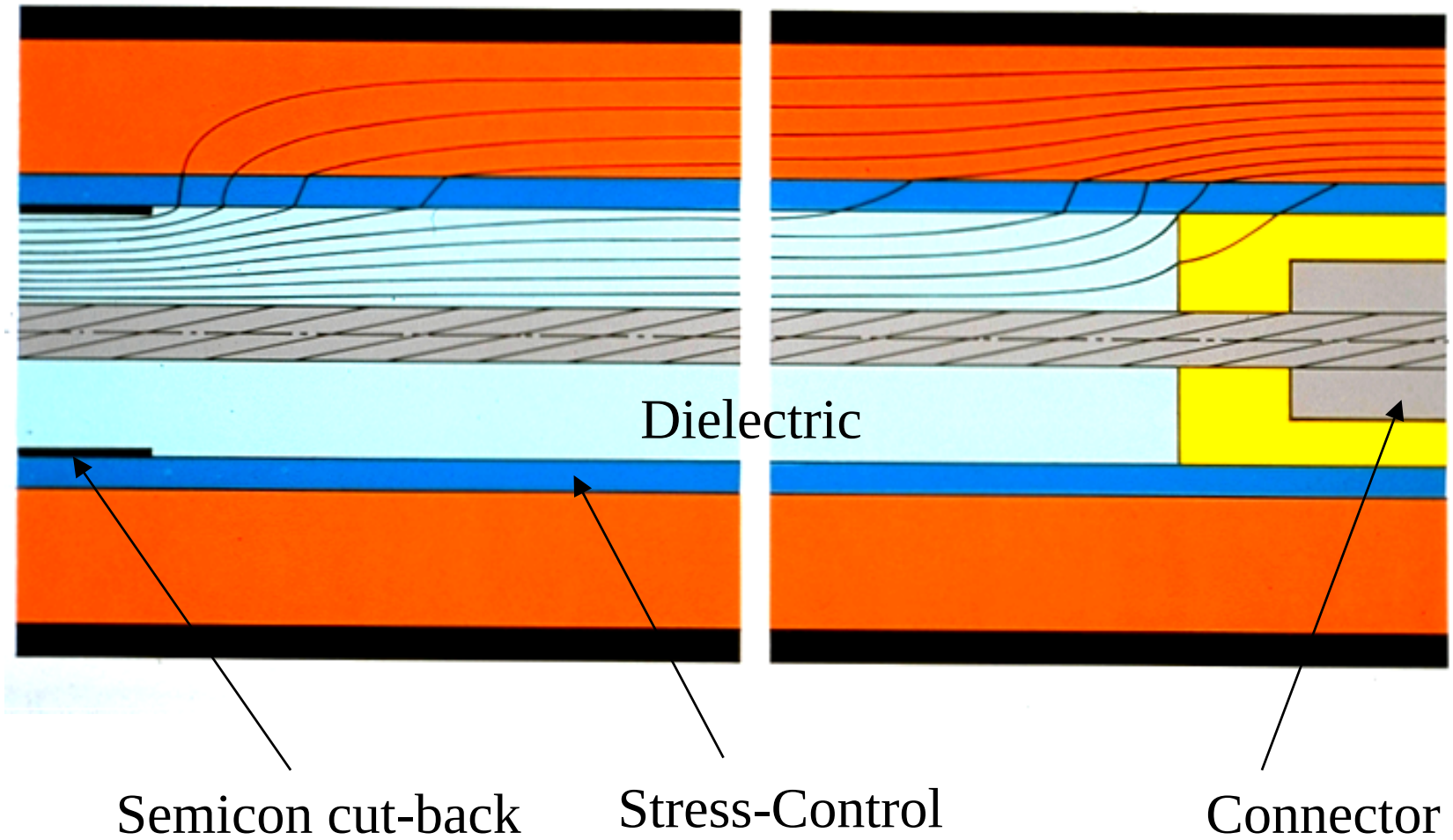
Specific Impedance vs Vol. Res. in Joints



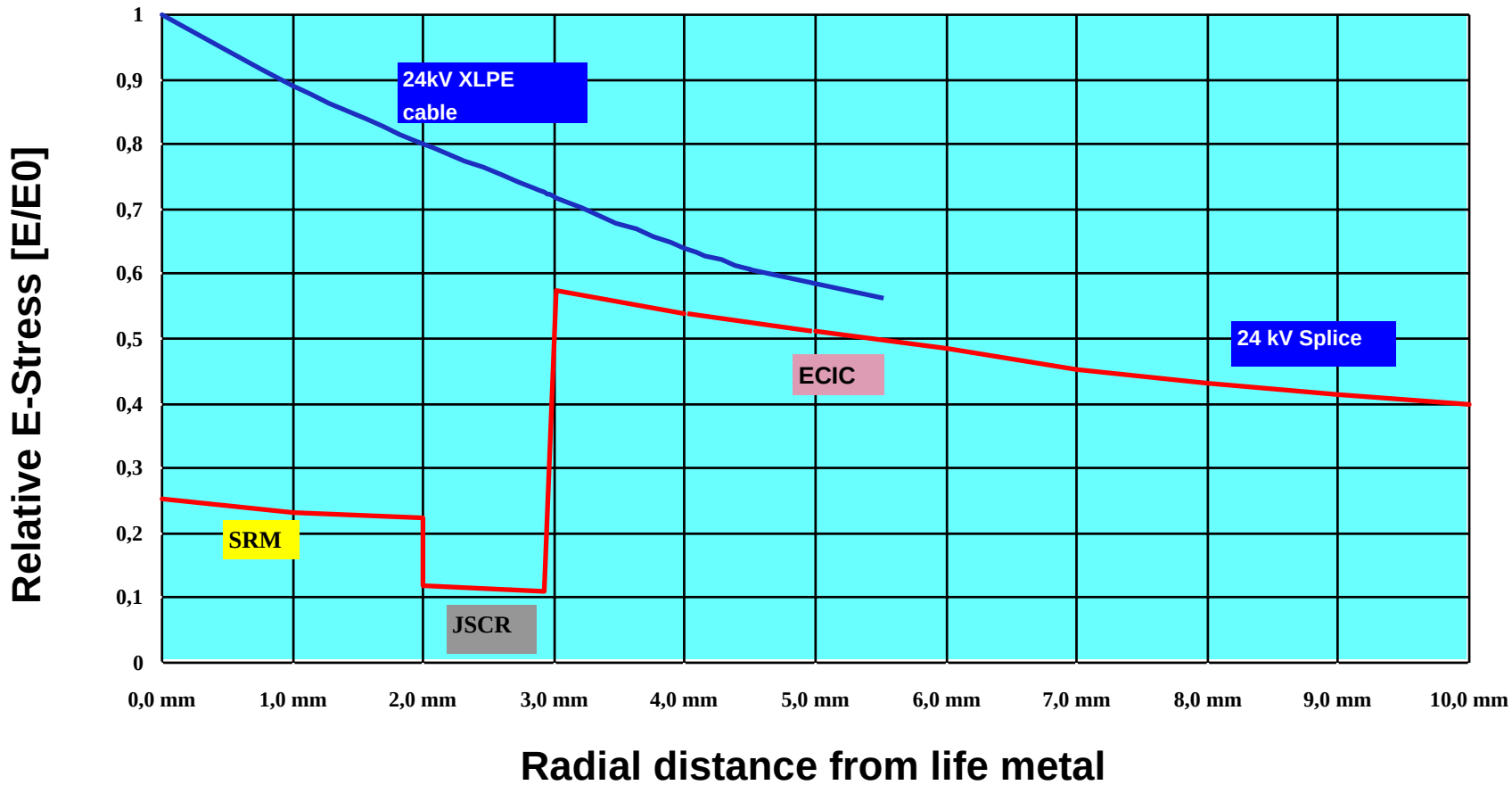
H/S Joint for 24kV



Potential Distribution

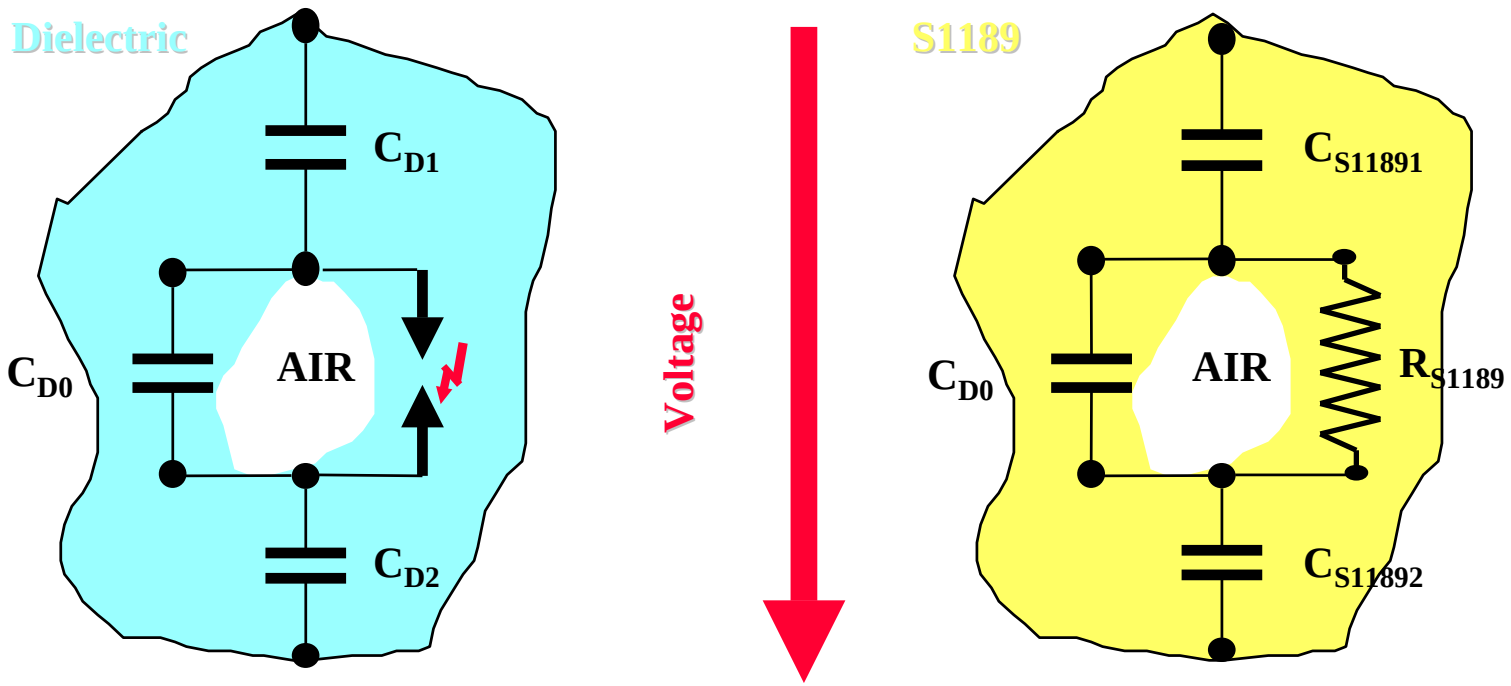


Radial Field Distribution in Joints



Void Filler S1189

- Discharge Extinguisher
  - R_{S1189} prevents discharge inception voltage



C_{DX}= fraction Capacitance Dielectric

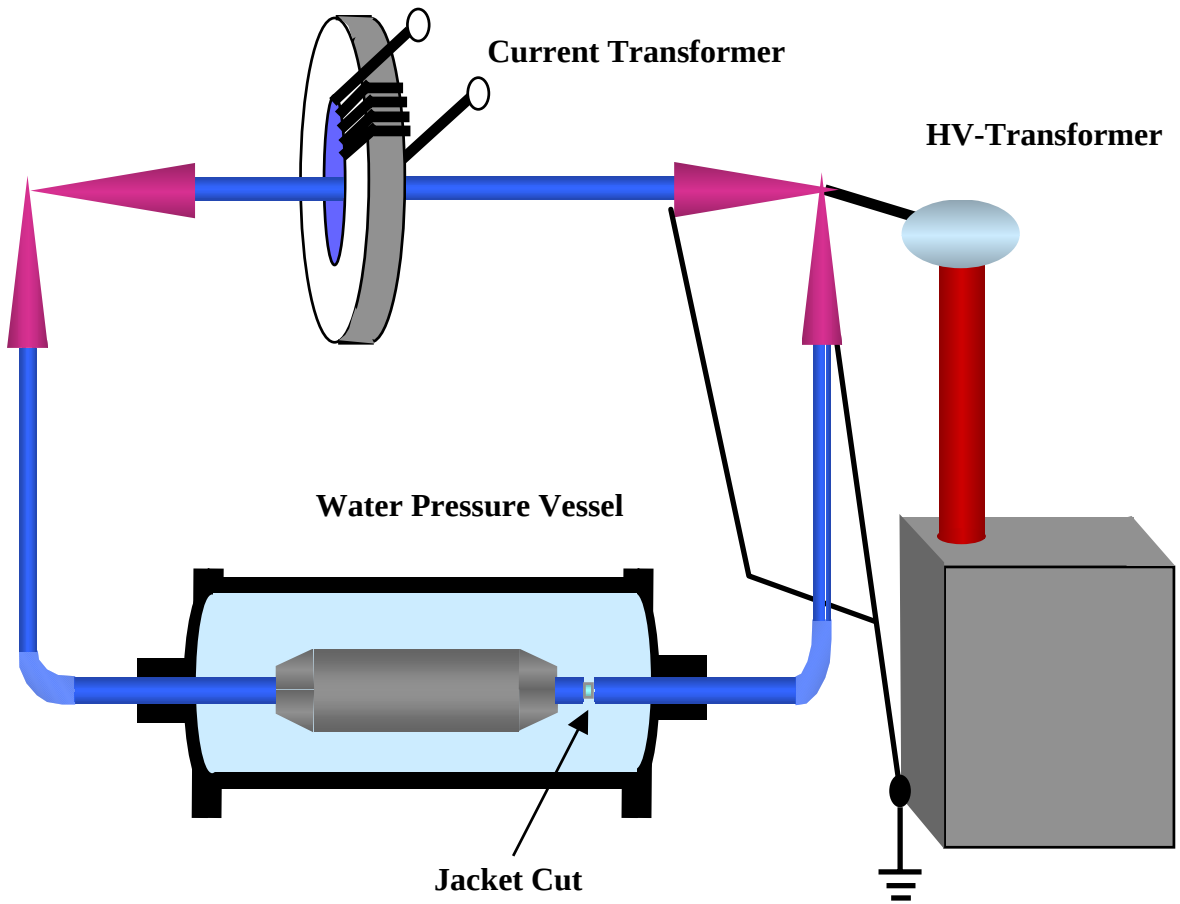
C_{S1189X}= Fraction Capacitance S1189

Hardware Verification

- Material tests
  - Tensile strength
  - Elongation
  - Thermal endurance
  - UV resistance to tracking and erosion
  - Weather stability

- Component tests
  - Connector tests
  - Repetition of material tests on finally shaped material

Water Pressure Test



Test Conditions

1000h Loadcycling

2.5 xV_0

Pressusre rate:

100kPa/100h
up to 500kPa

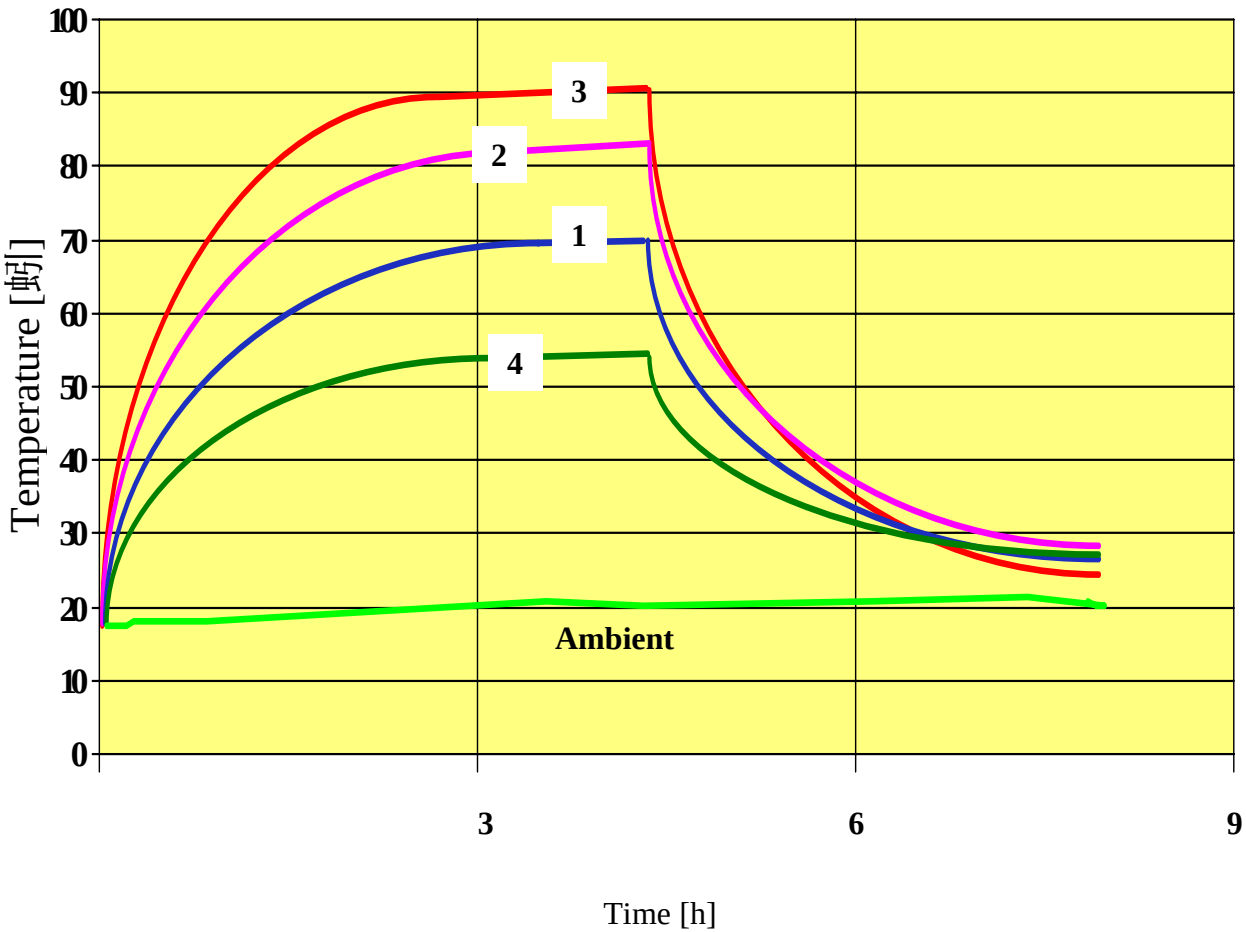
Design Verification

- Design test
  - Type tests with increased values, combined with various severe operational conditions
    - Cycling with water in the conductor strands
    - Cycling with internal and external water pressure

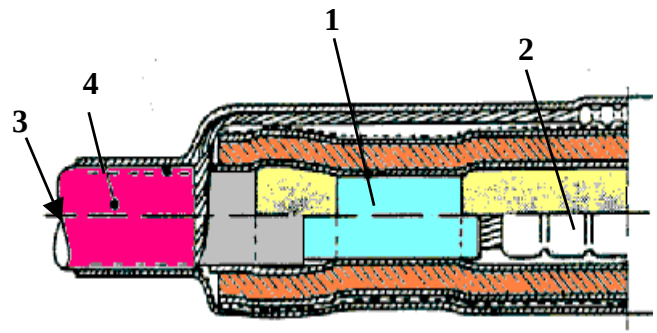
- Lifetime tests
  - Operation simulation under accelerated condition
    - load-cycling in air and immersed in water
    - Criteria
      - Remaining life-time
      - Time to failure
- Qualification
  - Type test to standards

R

Load Cycling in Air



Thermo-Couple



1 Cable Dielectric

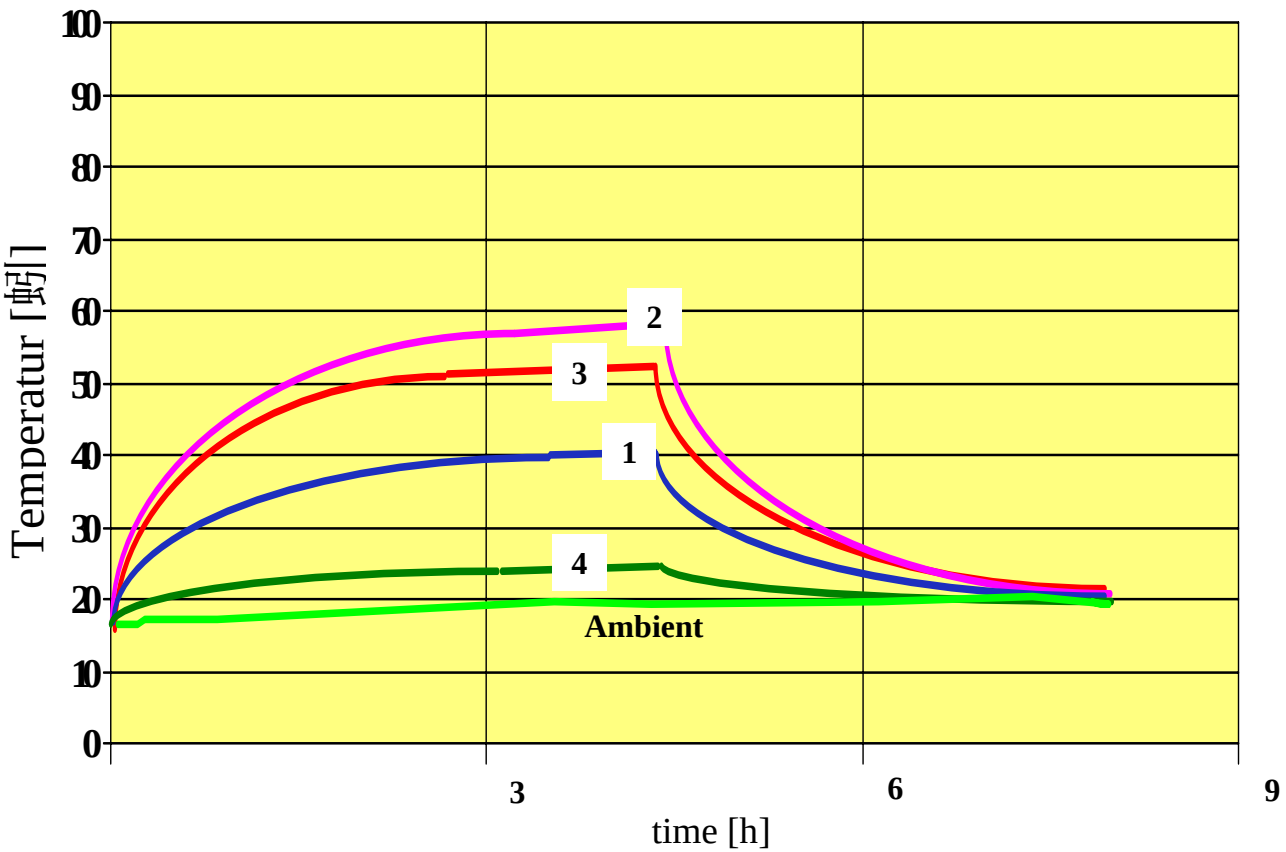
2 Connector

3 Cable Conductor

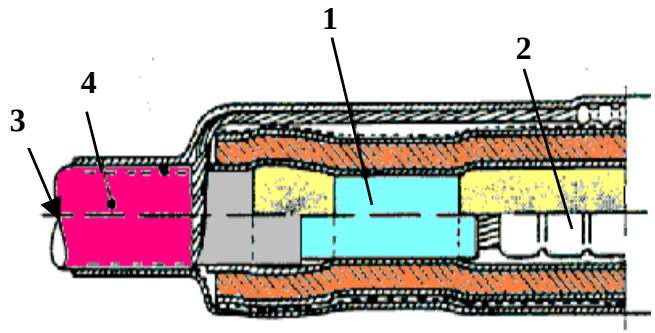
4 Outside Cable Jacket

Cable: 24kV XLPE 150mm²
Steady current I= 483A

Load Cycling in Water



Thermo-Couple



1 Cable Dielectric

2 Connector

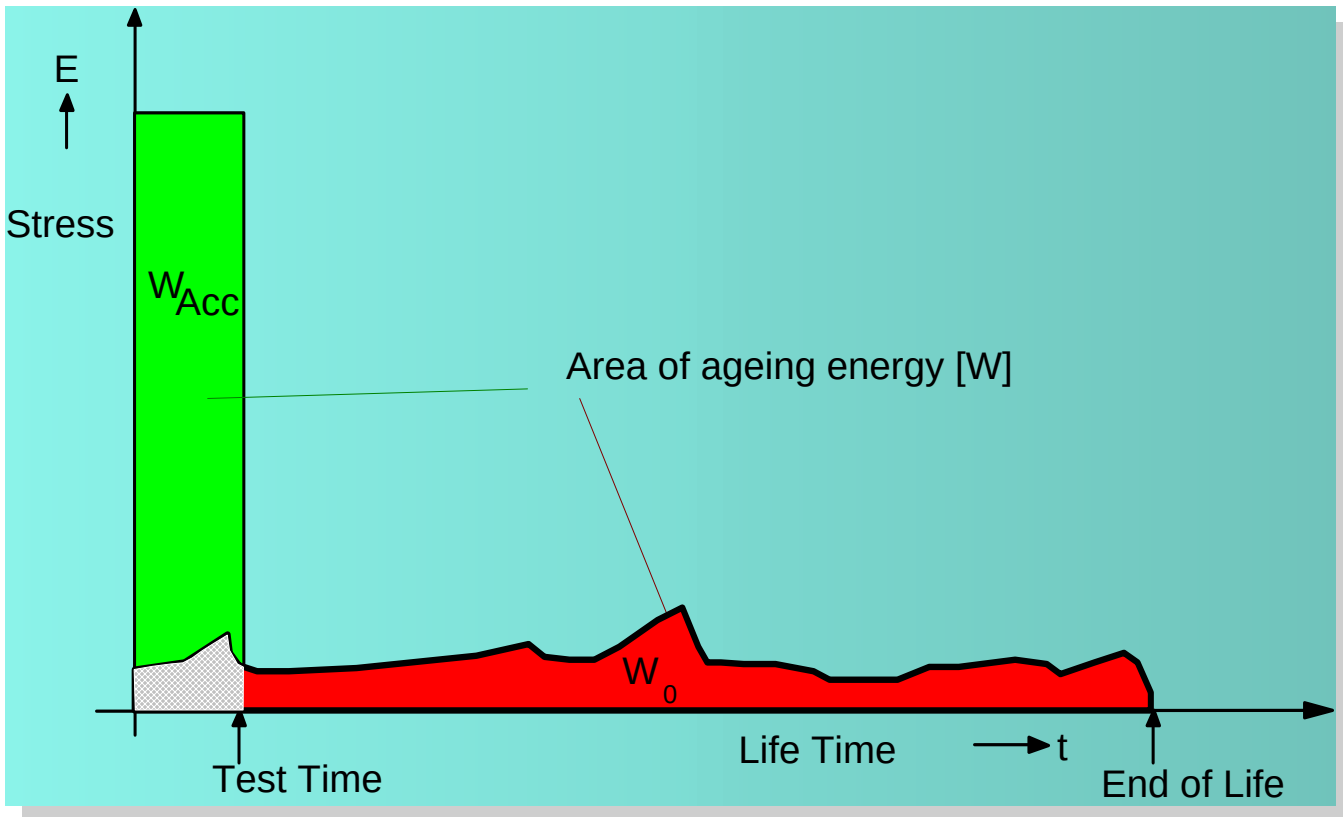
3 Cable Conductor

4 Outside Cable Jacket

Cable: 24kV XLPE 150mm²
Steady current I= 483A

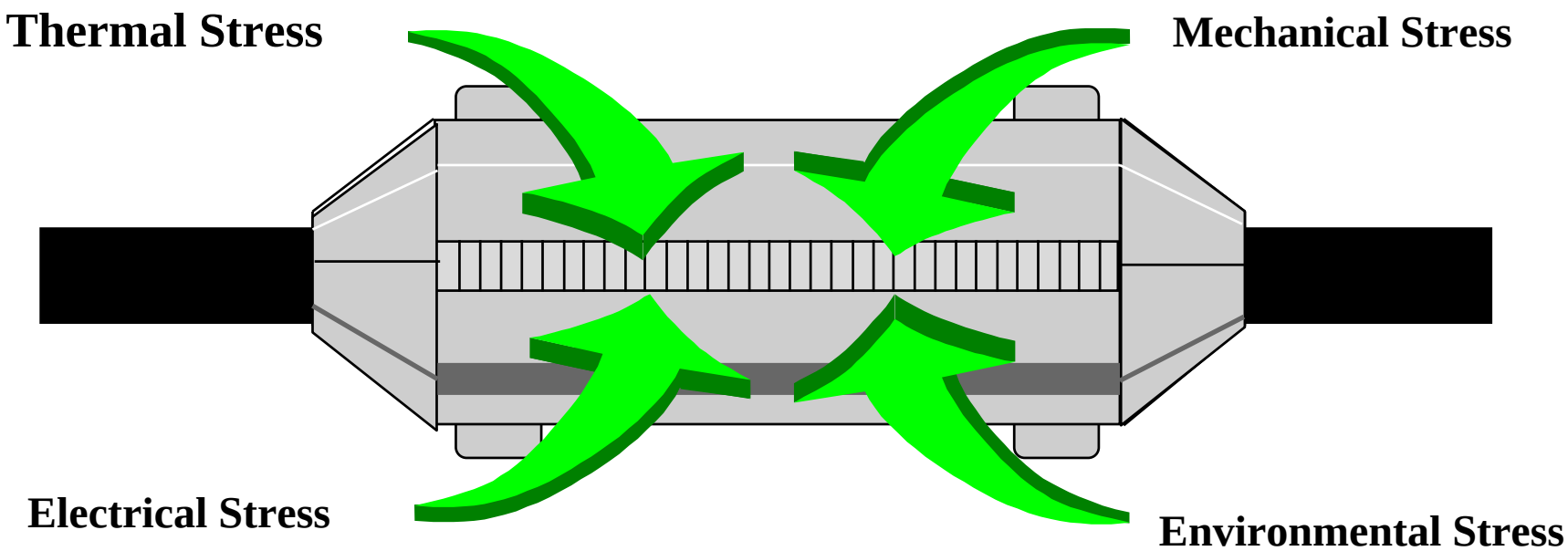
Life Time Study

- Ageing Simulation:
  - using the equivalent Energy -Amount as under Natural Conditions

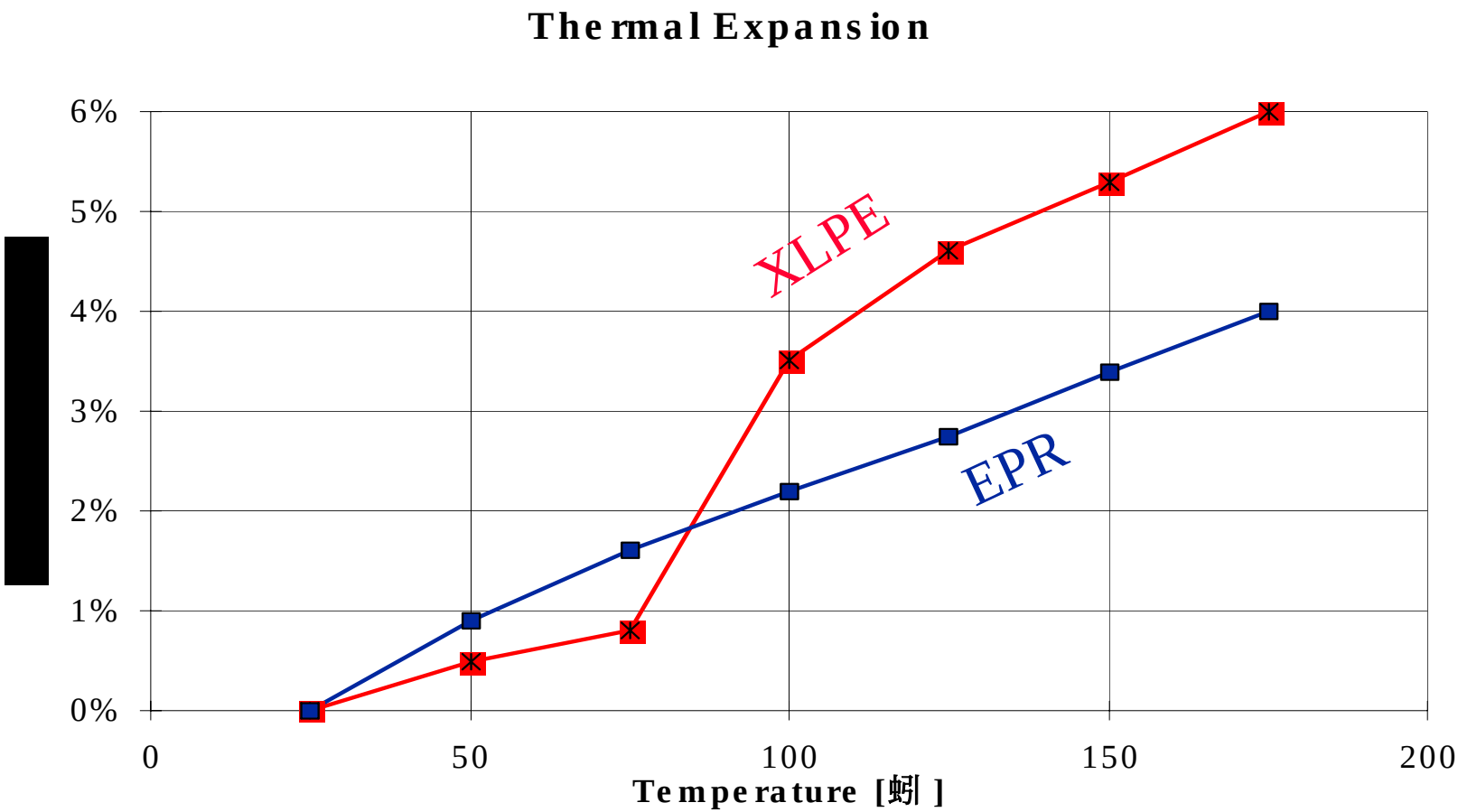


Ageing Factors

- Cable Accessories are subjected to various Stress Combinations



Material Characteristics (Insulation)

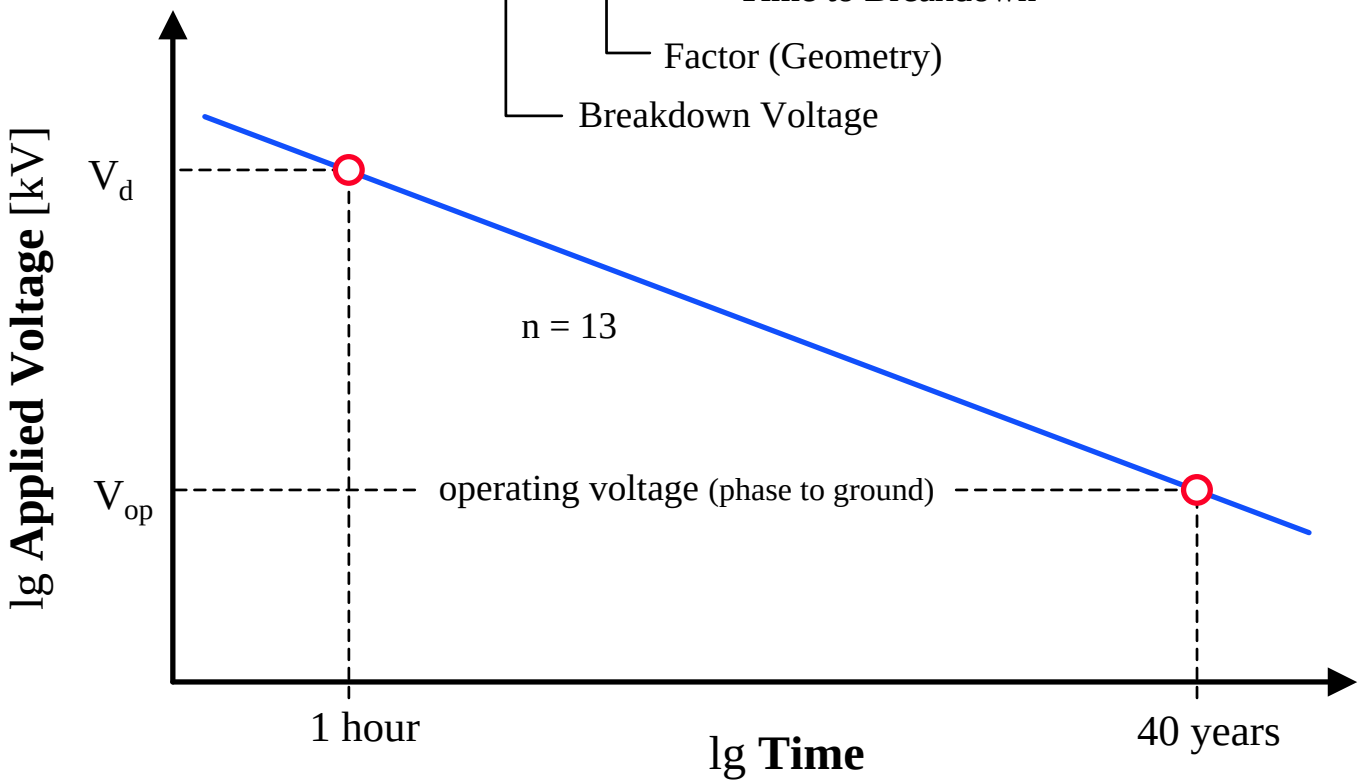


Life Time and Power Law

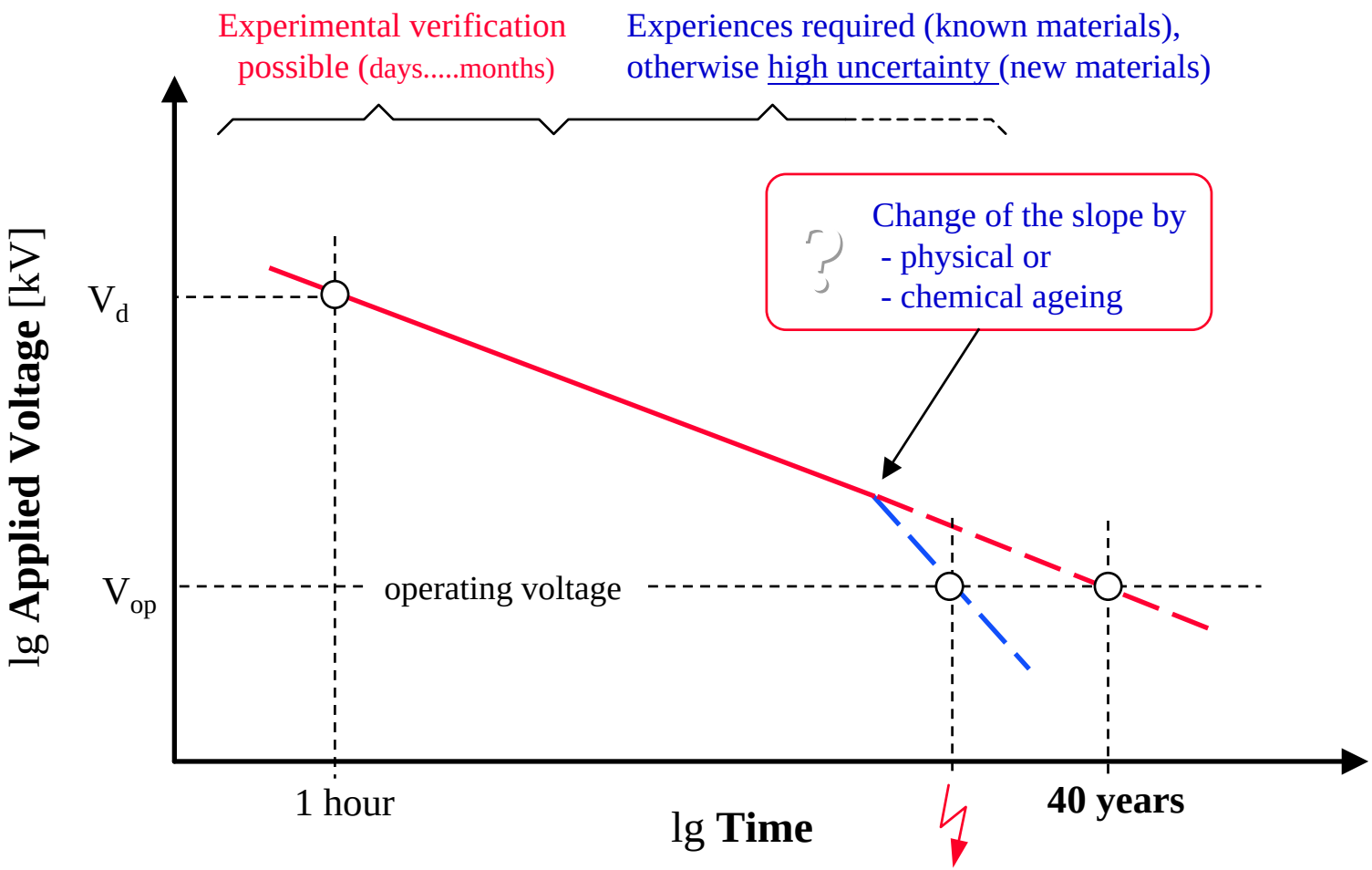
Power Law:

$$V_{BR} = k \cdot t_{BR}^{-\frac{1}{n}}$$

- V_{BR}: Breakdown Voltage
- k: Factor (Geometry)
- t_{BR}: Time to Breakdown
- n: Life Time Coefficient

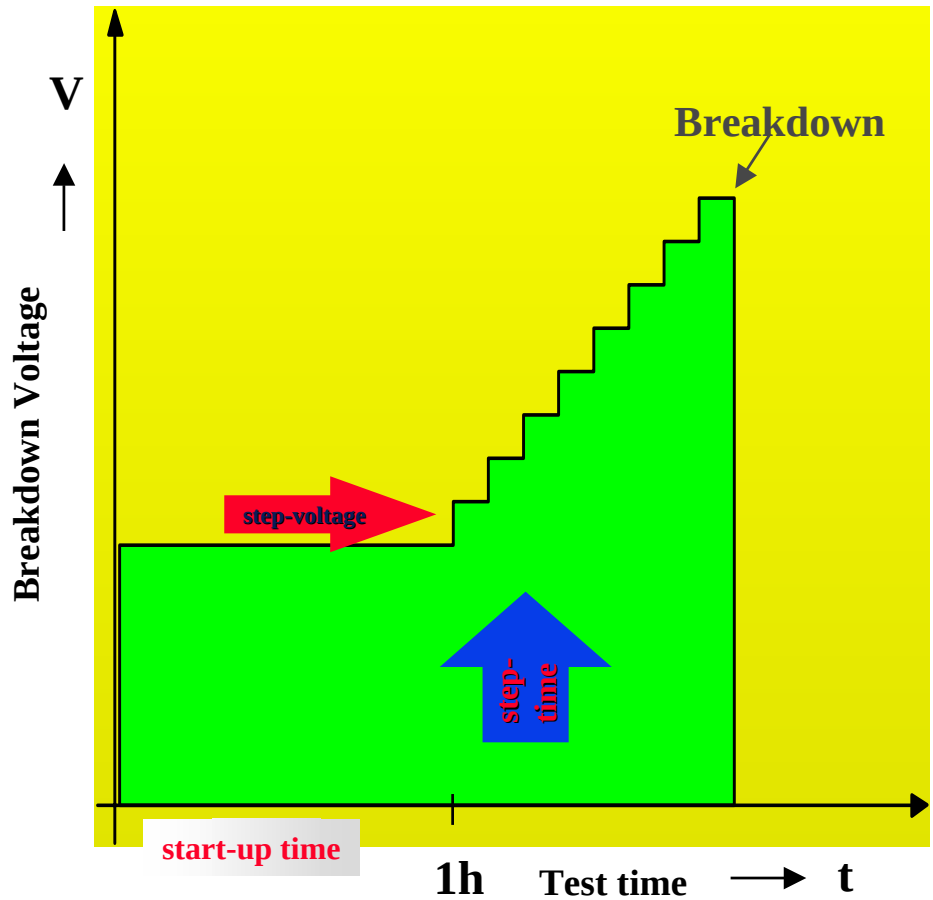


Life Time Estimation

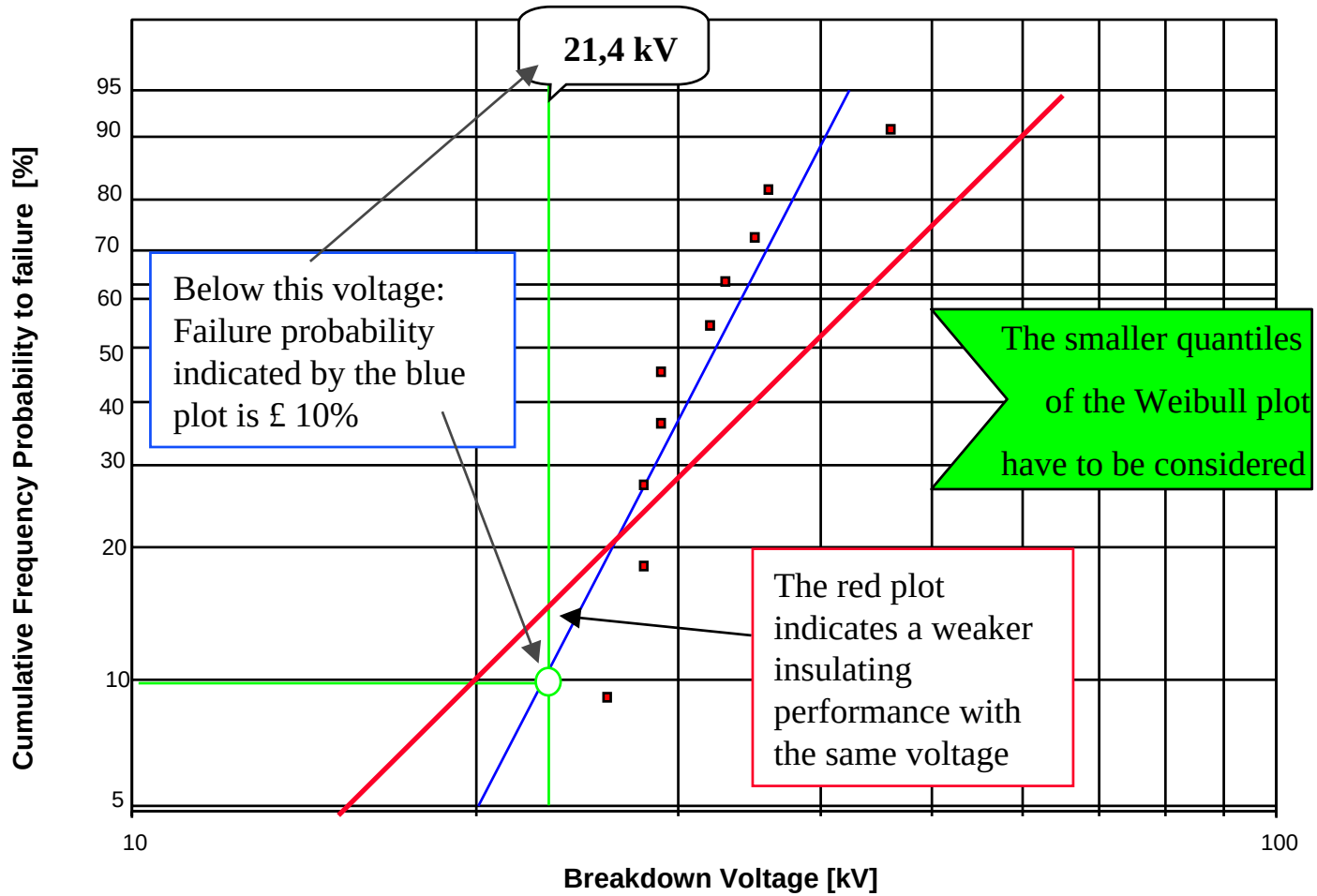


Step Test

- Determines remaining life-time of electrical insulation material.
  - Electrical stress increased through defined steps until insulation break-down is reached.
    - Tests will be carried out with various samples through stepwise rising voltage.
    - Results will be evaluated statistically



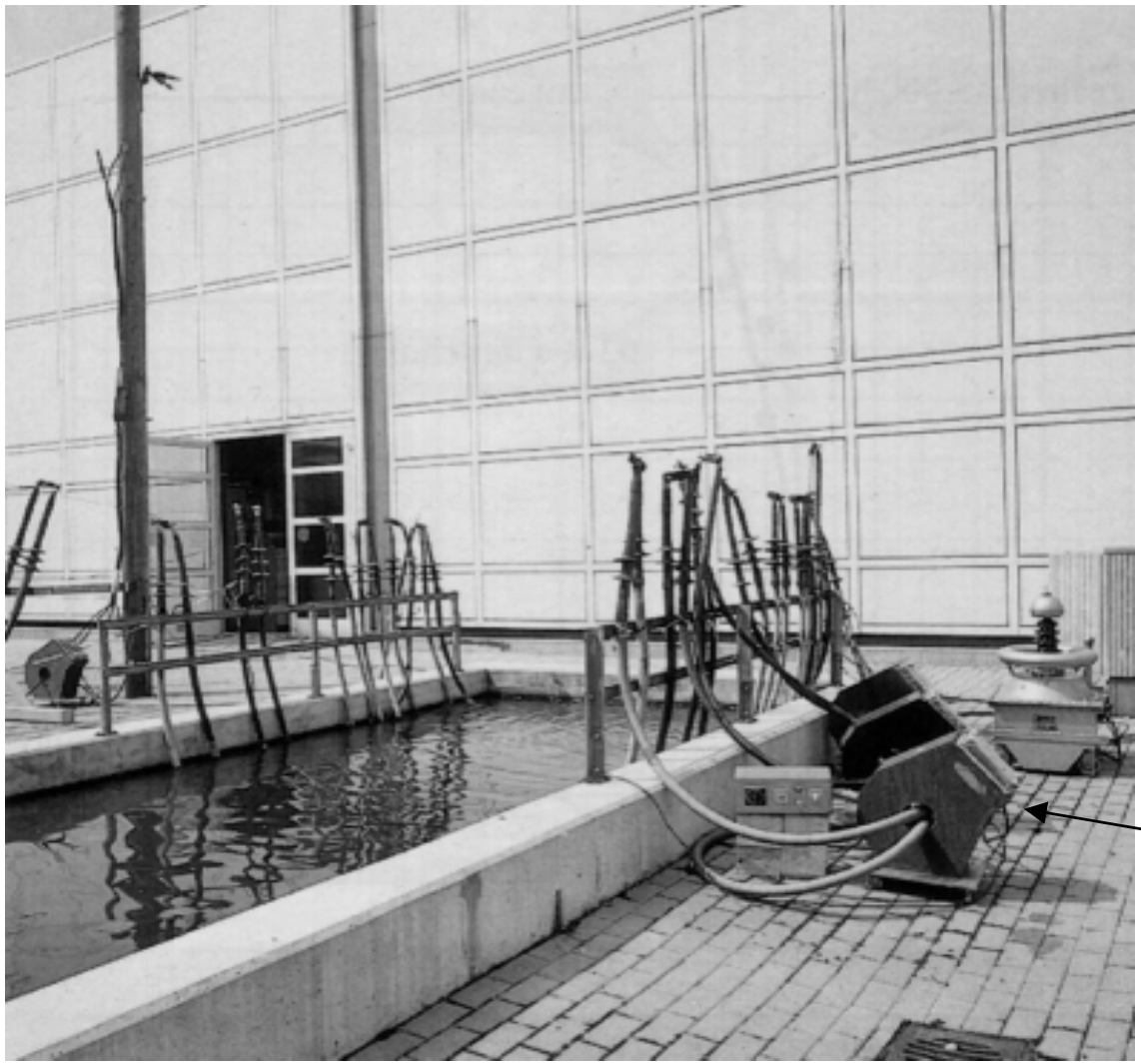
Interpretation of Test Data - Weibull Plot



Profile Tests

- Conditions for more than 63310h
  - Continuous voltage 40kVph-grd
    - Êmax=~115kV/cm
  - Load cycles 5h/3h
    - current adjusted to 95°C conductor temperature in air at 23°C ambient
  - Water had direct access to splices

Long-Term Test Set-up

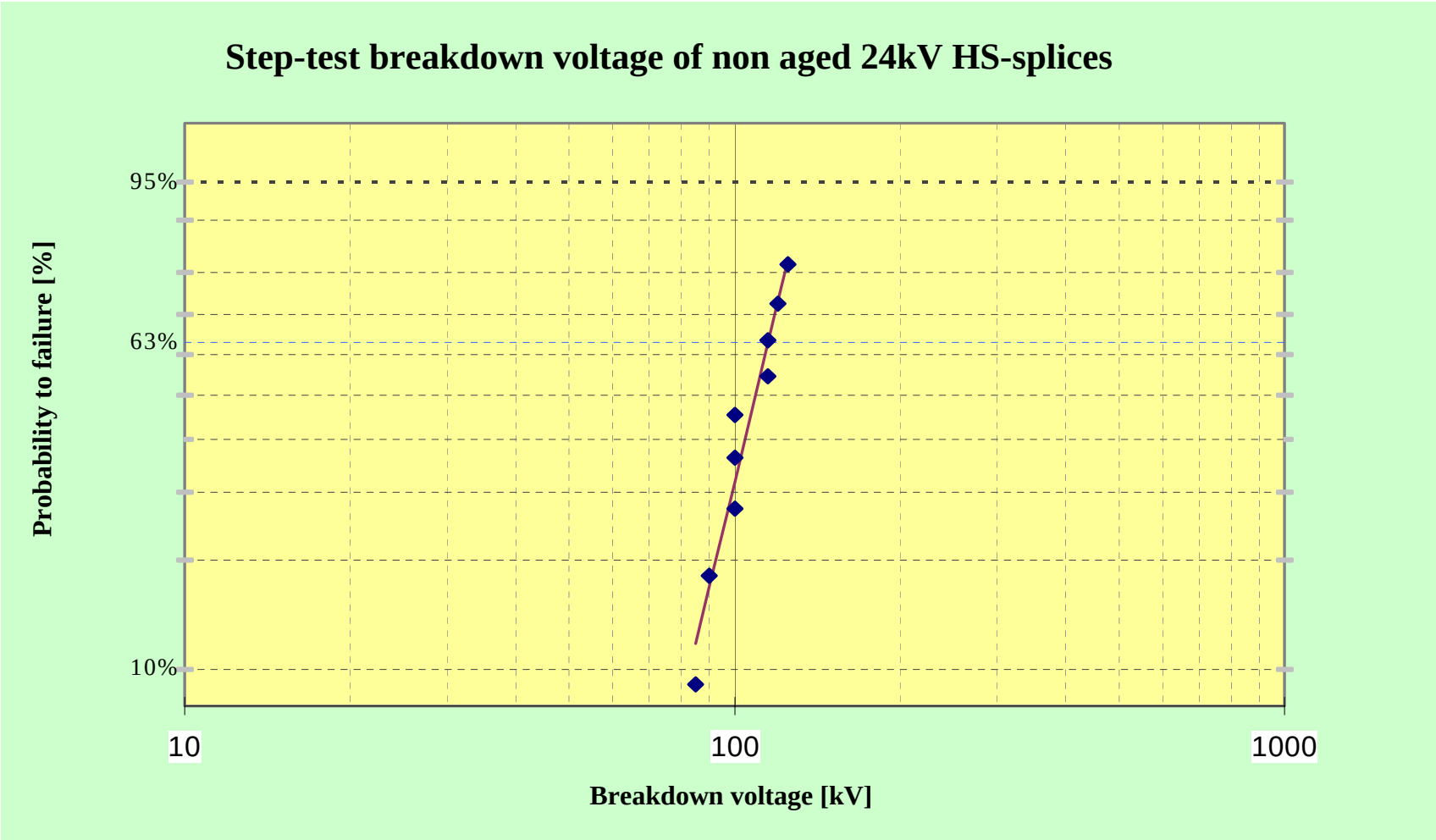


Test arrangement at the outside test field

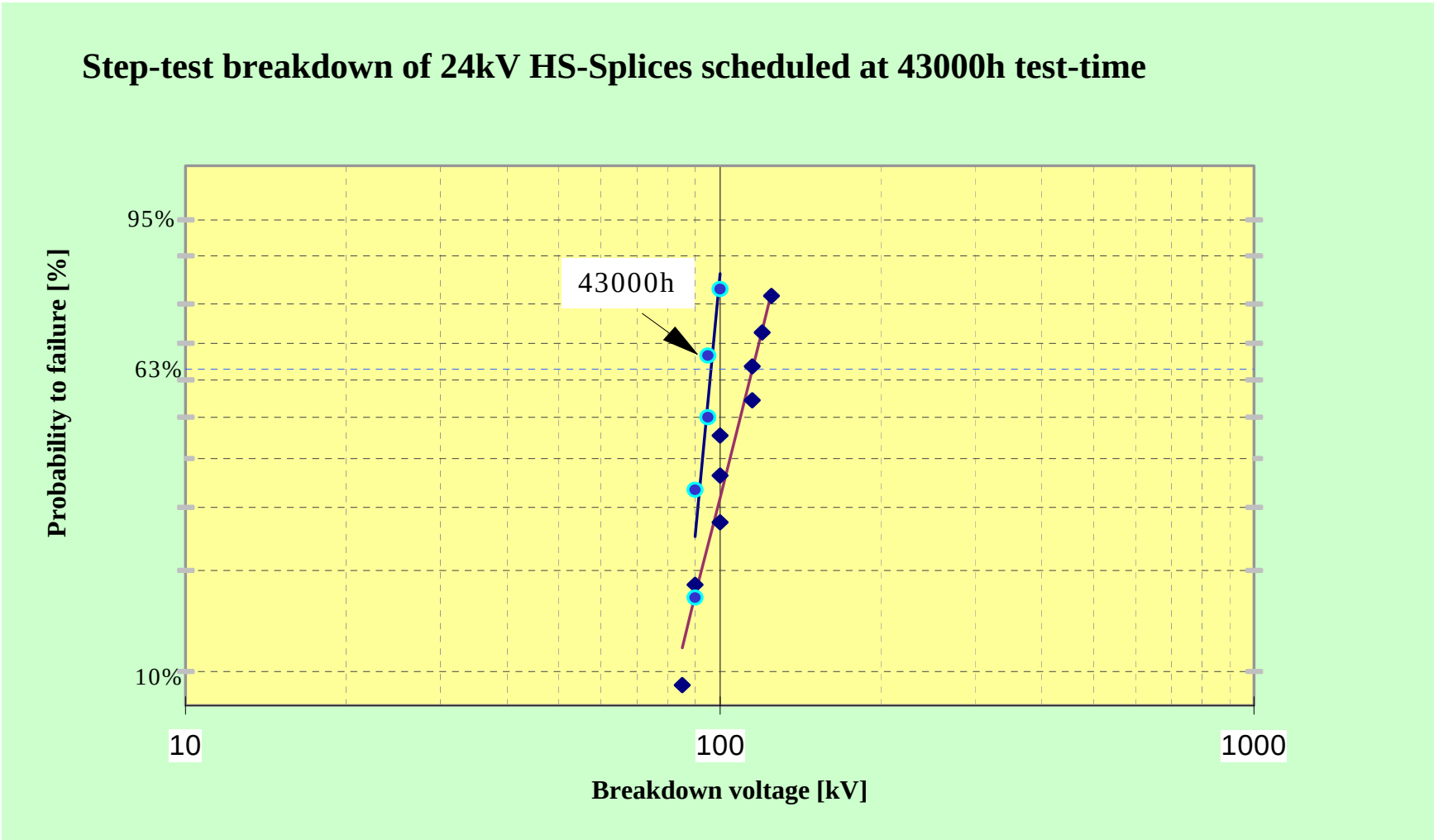
HV-Transformer
$V_{ph\text{-}grd}$ =40kV

Current Transformer

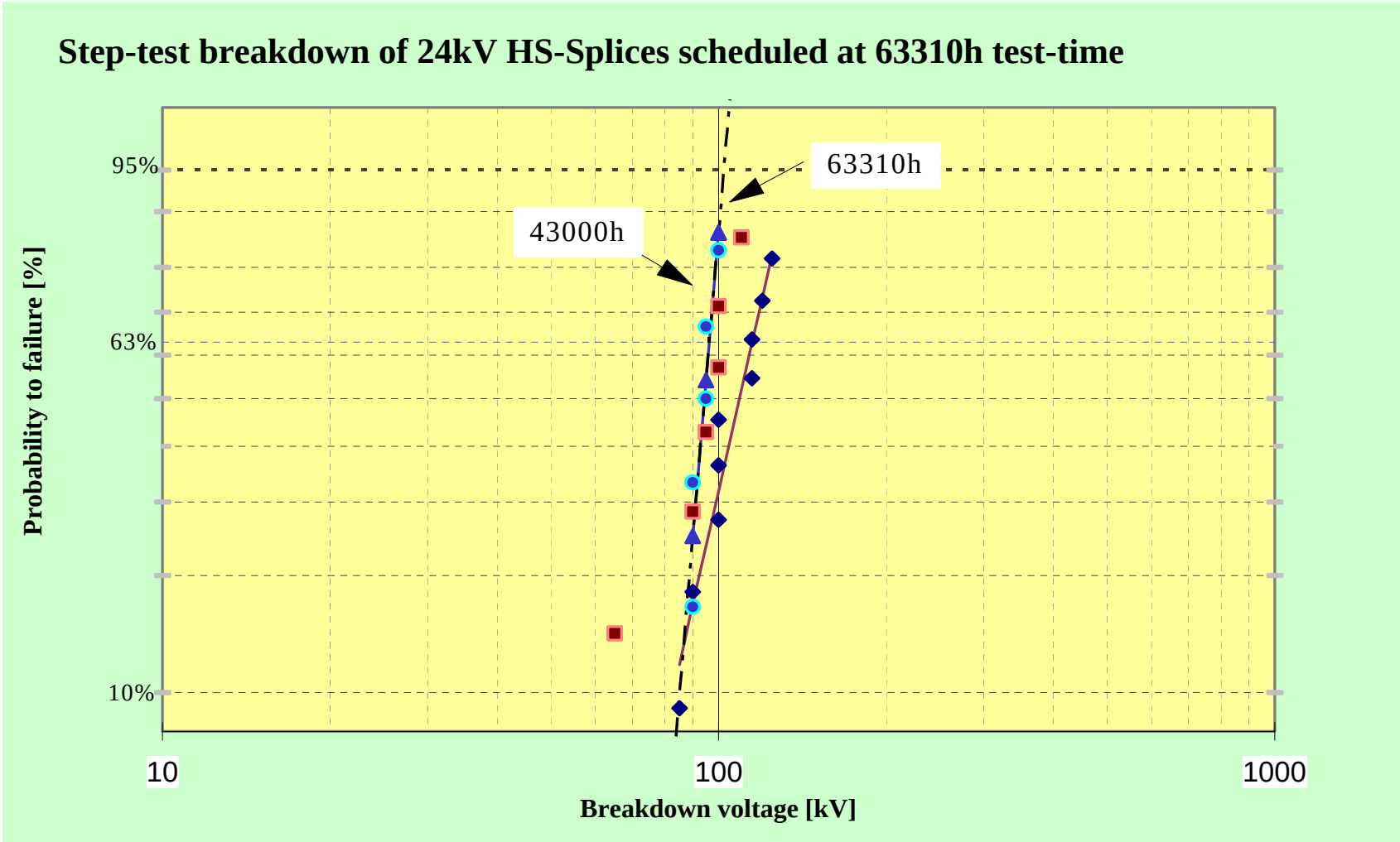
Weibull Plot of non aged HS-Joints



Weibull Plot of HS-Joints after Ageing



Weibull Plot of HS-Joints after Further Ageing



Qualification

Short Pre-Test Program

- The program consists of two major parts
  - 1. Short term pre-evaluation test
    - evaluate the product design
    - establish design acceptance criteria
  - 2. Product qualification and compatibility test
    - Product qualification test and customer audit

Screening Test

Short Test 10 and 20 kV in accordance with WEW Standard

Test A: Non-draining compound
Test B: Synthetic material

	Test	6/10 kV	12/20 kV	Result
1	Partial Discharge (PD) inception/exception(DIV/DEV)	28 KV 1	50kV 1	2Uo (12/24kV) ≤ 10pC
2	DC Voltage Withstand	48KV 15	96kV 15	No breakdown or flashover
3	Lightning Impulse Voltage	75kV 10+/-	125 10+/-	1 Flashover per +/- allowed
4	Partial Discharge (PD) inception/exception(DIV/DEV)	28kV	50kV	2Uo (12/24kV) ≤ 10pC
5	9 Load cycling, Test Voltage in accordance with VDE 0278-0298	17,5kV	35kV	No breakdown or flashover
6	Partial Discharge (PD) inception/exception(DIV/DEV)	28kV	50kV	2Uo (12/24kV) ≤ 5pC
7	Lightning Impulse Voltage	75kV 10+/-	125 10+/-	1 Flashover per +/- allowed
8	DC Voltage Withstand	48KV 15	96kV 15	No breakdown or flashover
9	AC Voltage Withstand	A: 30kV 4 Std. B: 35kV 4 Std.	A: 40kV 4 Std. B: 55kV 4 Std.	No breakdown or flashover
10	Step Test	5kV/Std.	10kV/Std.	Until Breakdown

Points 1 to 9 must pass. According to experience, the full test can only pass when at least 1 level in the Step Test is passed

Acceptance Test Program

Full Test for 10kV Interior-Cable facilities in accordance with WEW Standard (Number of the tests in accordance with VDE)

Test A: Non-draining compound
Test B: Synthetic material

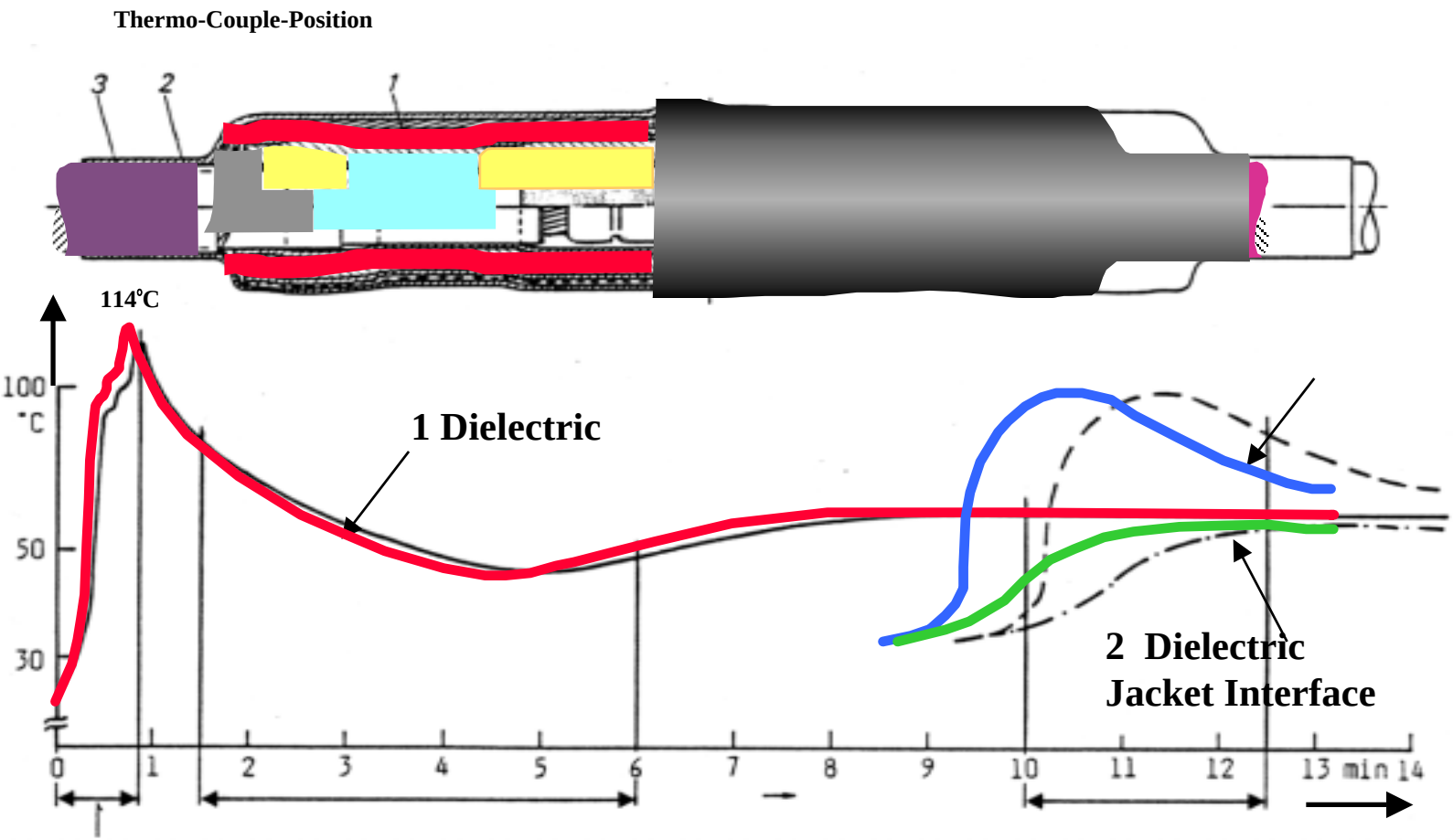
Test No.	Test	Test according to VDE 0278/Part 1-4/Feb.91 with extra tests in acc. with WEW	Test values	Result
1	A	Load current of shield	60 A / 8h	
2	A B	A.C. voltage withstand	28kV / 1min 35kV / 5min	No breakdown No flashover
3	A	tg σ - Messung	2,9kV 7,25kV 11,6kV	Informative
4	B	Partial Discharge (PD) inception/exception(DIV/DEV)	15kV / 1min	No partial discharge > 10pC by 12kV
5	A B	Lightning Impulse Voltage	± 75kV 10 x each	No breakdown, 1 failure per +/- allowed
6	A B	Electrical heat cycling in air in acc. with VDE 278/298	17,3kV 3 Load cycles	No Breakdown

Acceptance test Program cont...

7	B	Partial Discharge (PD) inception/exception(DI V/DEV)	15kV / 1 min	No partial discharge 5pC by 12kV
8	A B	Electrical heat cycling in air in acc. with VDE 278/298	17,3kV 60 Load cycles	No breakdown
9	A B	Thermal short circuit (conductor)	2 x each conductor	No noticeable damage
10	A B	Electrical heat cycling in water / jacket cut	17,3kV 63 Load cycles	No breakdown
11	B	Partial discharge	15kV / 1 min.	No partial discharge > 5pC by 12kV
12	A	tg σ - Messung	2,9kV 7,25kV 11,6kV	Informative
13	A B	Lightning Impulse Voltage	$\pm$ 75kV 10 x each	No breakdown, 1 failure per +/- allowed

Installation Temperature

Thermo-Couple-Position



Installation Time Progress

JCSR- Shrinkage

ECIC- Shrinkage

Outer Sleeve - Shrinkage

Summary

- The achieved results during design studies and life-time studies verify in its complexity the widely accepted performance of today marketed MV cable accessories.