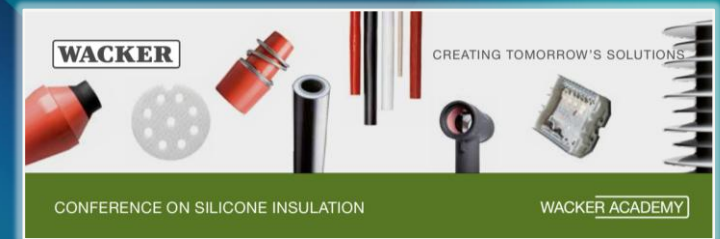


100

Years  
**THE POWER  
BEHIND POWER**



# Upgrading Composite Hollow Core Insulators for Alternative Insulation Gases

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# Agenda

- 1. Introduction and Motivation**
- 2. Alternative Insulation Gases**
- 3. Qualification and Testing of Material Compatibility**
- 4. New Joining Technologies**
- 5. Conclusion and Outlook**



# 1. Introduction and Motivation

- + SF<sub>6</sub> is currently / still the most important insulation gas for HV applications [1]:
  - High electrical strength
  - low condensation temperature
  - Chemical stability
  - Fast arc extinguishing behavior
  - ...
- + Downside: massive greenhouse potential **(23.900x that of CO<sub>2</sub>)**
- + European F-gas regulation VO (EU) 2024/573 [2]
  - SF<sub>6</sub> will be banned for HV applications in the next years.
  - Starting in 2035, only recycled SF<sub>6</sub> will be permitted.

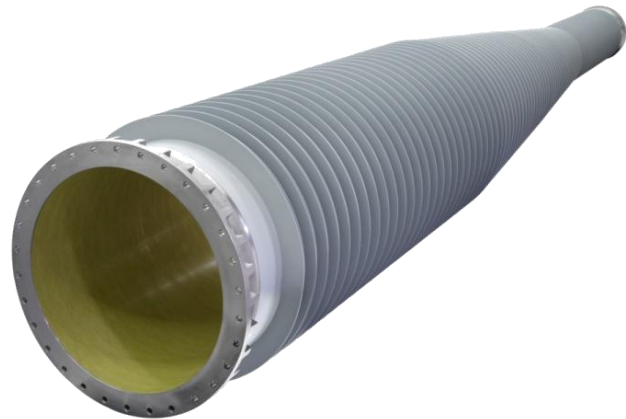
## Motivation

- + Eco-friendly and sustainable alternative insulation gases entering the market.
- + gas mixtures: carrier gases with fluoronitrile
  - ⇒ significant lower global warming potential
- + Challenges
  - Higher maximum service pressures
  - Strict requirements regarding tightness and diffusion
  - Chemical compatibility of HV equipment materials with alternative gases and its decomposition products



# 1. Introduction and Motivation

## ReCoTec® Qualification



→ **Production trial of processing thermoplastic films**  
Integration of additional diffusion barrier

→ **Analysis of diffusion and chemical resistance**  
HF immersion test

→ **Aging tests**  
Storage of materials in alternative gas atmosphere

→ **Development of new flange-tube-joint technologies**  
Strength testing of new joint concepts



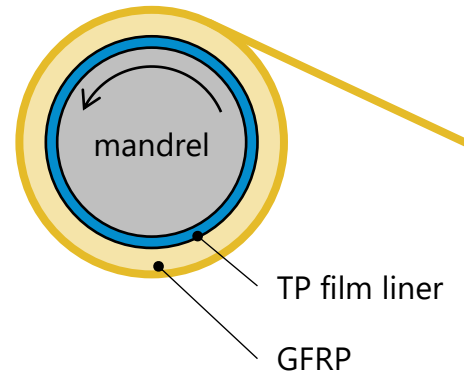
## 2. Alternative Insulation Gases

Requirements	Clean Air	Econiq®	g <sup>3</sup> ®
<ul style="list-style-type: none"><li>+ high-dielectric strength</li><li>+ good arc-quenching capability</li><li>+ high thermal conductivity</li><li>+ low boiling point</li><li>+ high vapor pressure at low temperature</li><li>+ compatibility with other materials</li><li>+ low GWP (global warming potential)</li><li>+ no ODP (ozone depletion potential)</li><li>+ low toxicity</li><li>+ non-flammable and non-explosive</li></ul>	<ul style="list-style-type: none"><li>+ Mixture:<ul style="list-style-type: none"><li>- N<sub>2</sub> (80 %)</li><li>- O<sub>2</sub> (20 %)</li></ul></li><li>+ Supplier / User: Siemens Energy</li><li>+ GWP-100: 0</li></ul>	<ul style="list-style-type: none"><li>+ Mixture: [4]<ul style="list-style-type: none"><li>- CO<sub>2</sub> (86,5 %)</li><li>- O<sub>2</sub> (10 %)</li><li>- C<sub>4</sub>F<sub>7</sub>N (3,5 %)</li></ul></li><li>+ Supplier / User: Hitachi Energy</li><li>+ GWP-100: 180</li></ul>	<ul style="list-style-type: none"><li>+ Mixture: [3]<ul style="list-style-type: none"><li>- CO<sub>2</sub> (95 %)</li><li>- C<sub>4</sub>F<sub>7</sub>N (5 %)</li></ul></li><li>+ Supplier / User: GE Renewable Energy</li><li>+ GWP-100: 390</li></ul>

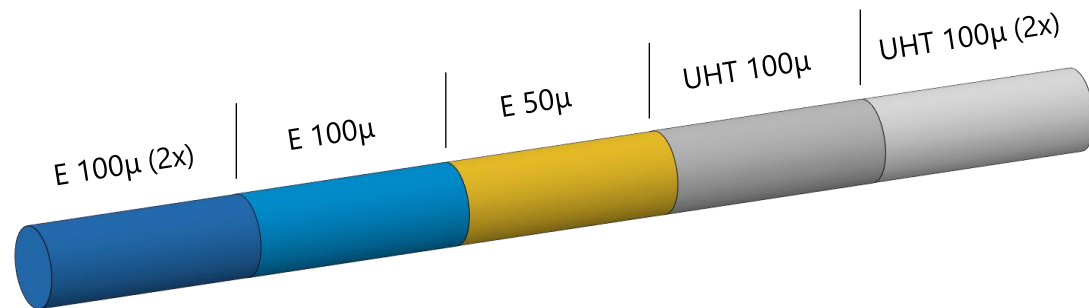
# 3. Qualification and Testing of Material Compatibility

## Processing Test of Thermoplastic Films

- + Structural core element of ReCoTec® insulators:  
GFRP tube (glass fiber-reinforced plastic)
- + Manufacturing technology: wet-filament winding
- + GFRP: heterogeneous material, compact and dense enough to prevent SF<sub>6</sub> or C<sub>4</sub>F<sub>7</sub>N from diffusion; smaller molecules are more critical.
- + Approach: Integration of a thermoplastic (TP) film liner as additional diffusion barrier



GFRP + liner specimens



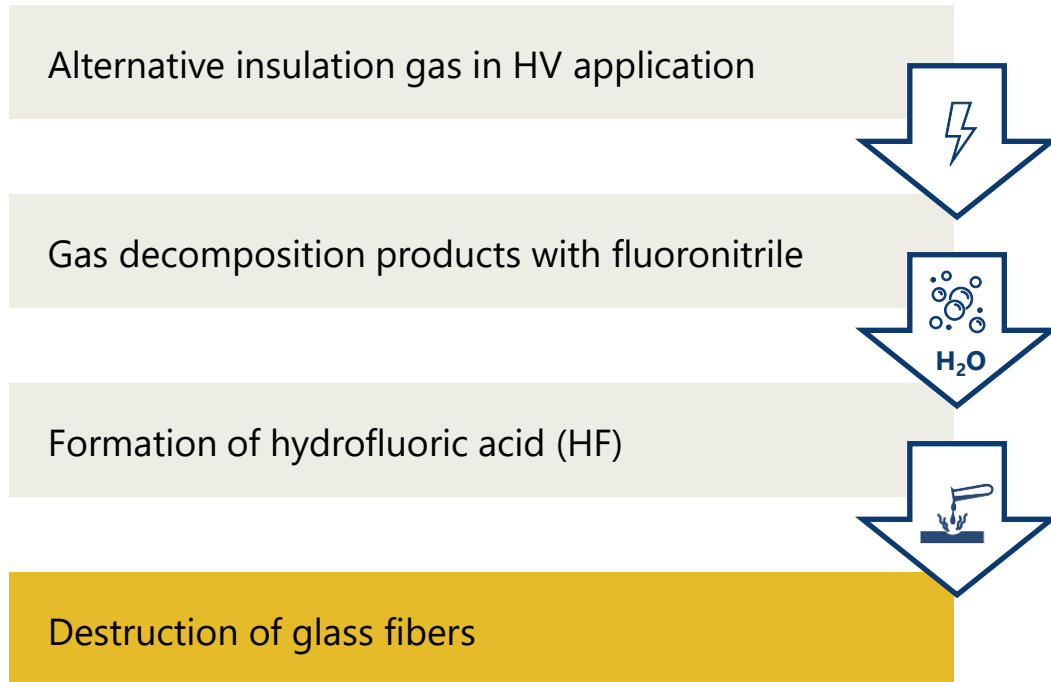
GFRP test tube with sections of different TP liner materials

Investigated TP films [5, 6, 7]

	E 50µ	E 100µ	UHT 100µ
<b>Materials</b>	PA, PE, EVOH	PA, PE, EVOH	PA, PP
<b>Thickness</b> [µm]	50	100	100
<b>Temperature resistance</b> [°C]	-25 / +100	-25 / +100	-25 / +121
<b>O<sub>2</sub> permeability</b> [cm <sup>3</sup> /m <sup>2</sup> ·bar·24h]	3	3	39
<b>N<sub>2</sub> permeability</b> [cm <sup>3</sup> /m <sup>2</sup> ·bar·24h]	1	1	6
<b>CO<sub>2</sub> permeability</b> [cm <sup>3</sup> /m <sup>2</sup> ·bar·24h]	10	8	120

# 3. Qualification and Testing of Material Compatibility

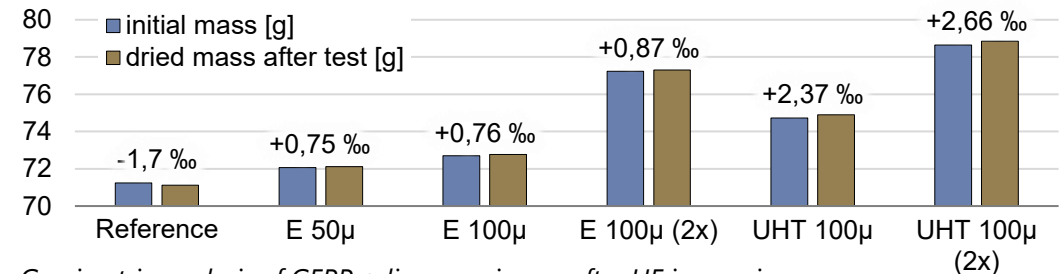
## Immersion Test in HF Solution



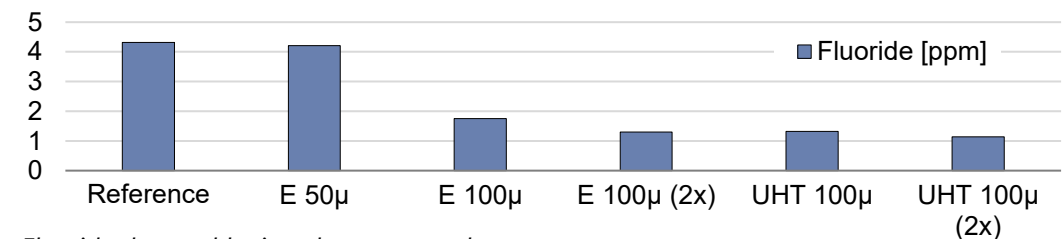
⇒ Immersion test in HF solution with GFRP + liner specimens as worst-case scenario

### Immersion Test in HF Solution

- + 5 % HF solution, room temperature, 48 h duration
- + Gravimetric analysis + ion chromatography



Gravimetric analysis of GFRP + liner specimens after HF immersion



Fluoride detected by ion chromatography

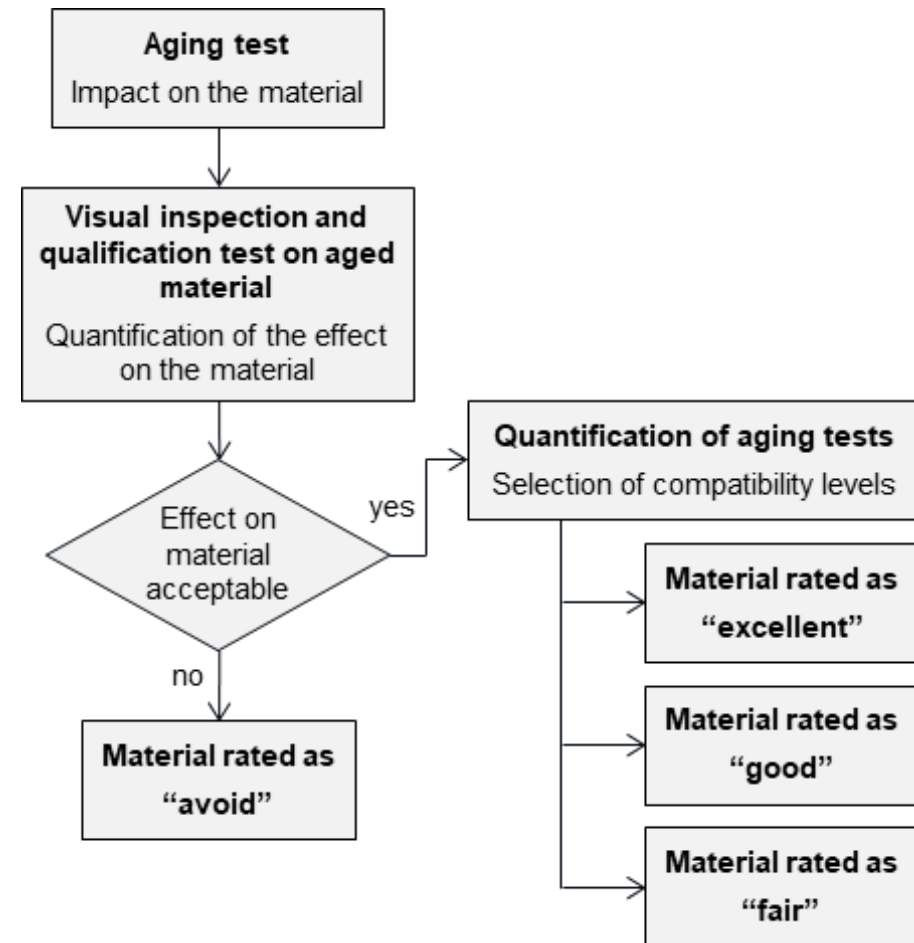
# 3. Qualification and Testing of Material Compatibility

## Aging Test

- + Investigation of chemical resistance and compatibility between alternative insulation gases and insulator materials
- + ReCoTec® qualification approach: gas chamber equipped with electrode pair inside for controlled arcing generation to produce decomposition products of gas atmosphere
- + Qualification scheme acc. to CIGRE TB 802 [8]



Examples of gas chambers / pressure containers for aging tests [8]



# 4. New Joining Technologies

## Type Tests

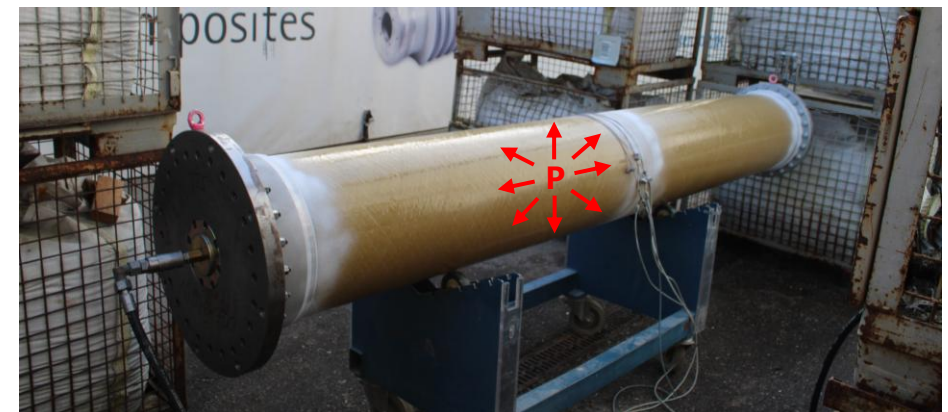
+ Verification of new composite hollow core insulator designs by mechanical type tests acc. to. IEC 61462 [9]:

	Internal pressure test IEC 61462, 8.4	Bending test IEC 61462, 8.5
Stage 1	2 x MSP	1 x MML
Stage 2	4 x MSP	1,5 x MML
Stage 3	up to failure (optional)	2,5 x MML
Stage 4	-	up to failure (optional)

- + Proper and reliable joining technology / design of metal flanges and GFRP tube is essential to withstand mechanical type test loads.
- + Development of advanced joint concepts to meet rising strength requirements



Bending test



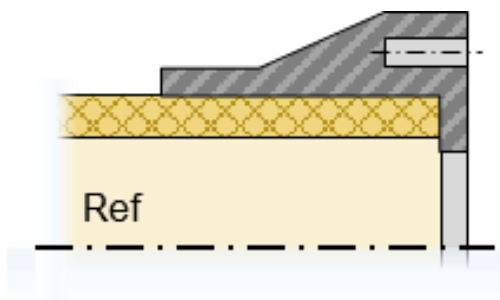
Internal Pressure Test

# 4. New Joining Technologies

## Joint Design Concepts

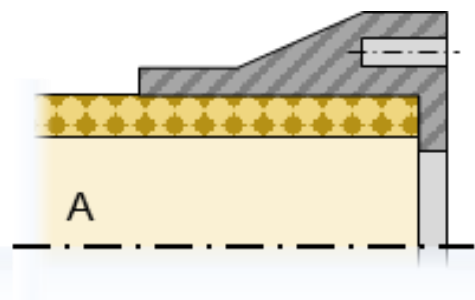
### Reference

- + Shrink-bonded joint
- + Structural epoxy adhesive
- + Shrink fitting enhances bonding



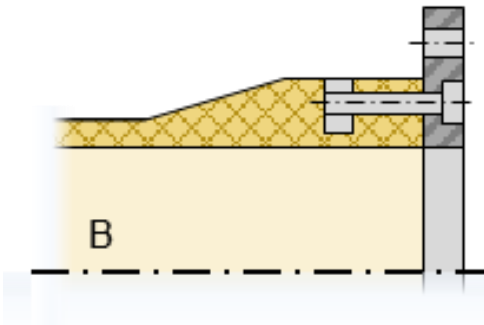
### Fabric Reinforcement

- + Same design as reference
- + Laminate reinforcement with glass fiber fabric



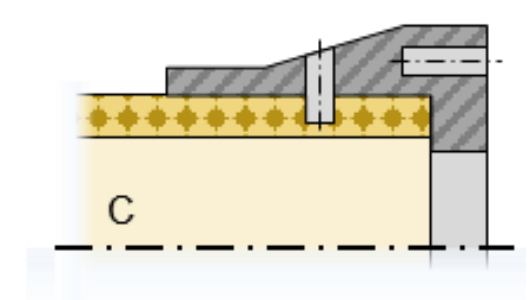
### Longitudinal Bolt

- + Tension rod connection
- + Simplification of flange design
- + No adhesive needed



### Radial Pin

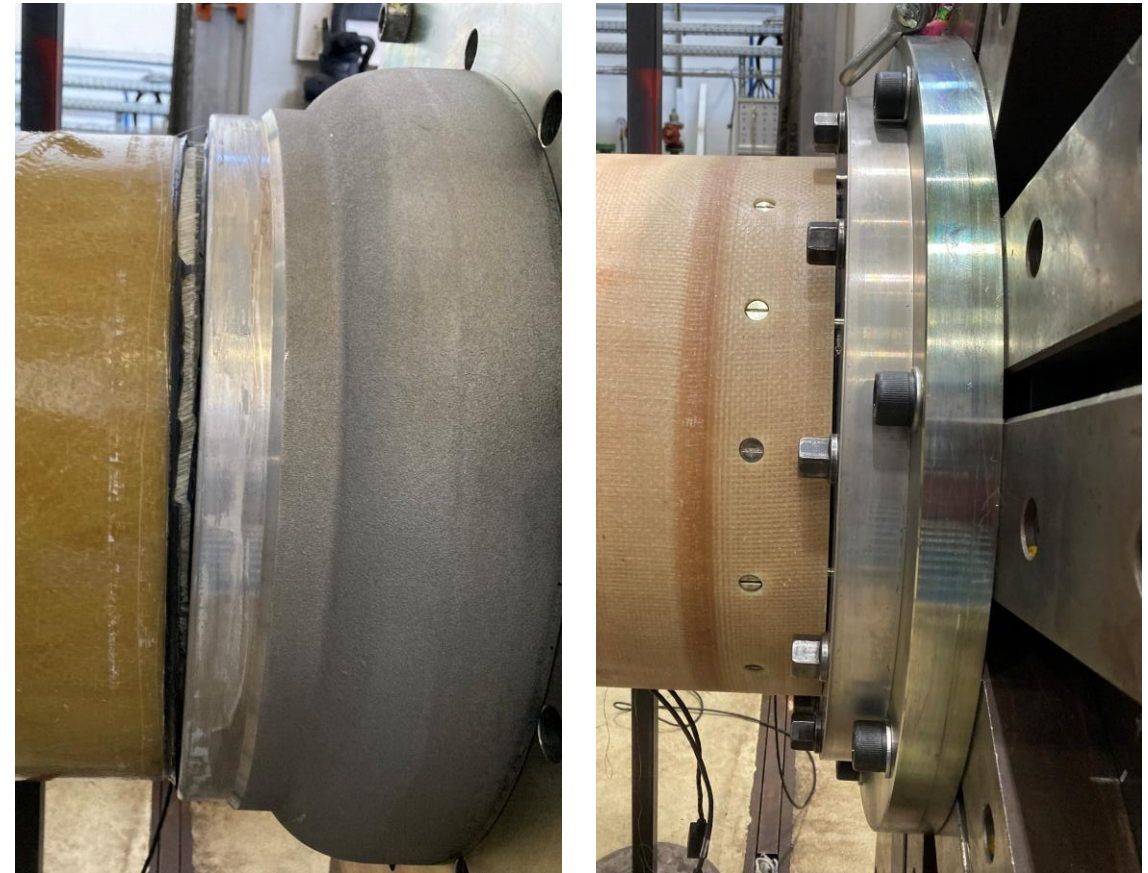
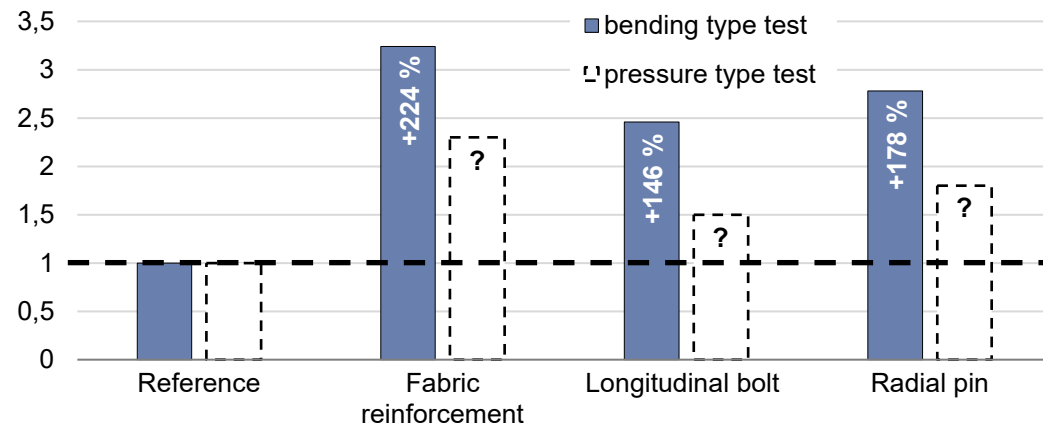
- + Fabric-reinforced GFRP laminate
- + Circumferential radial pins as additional support



# 4. New Joining Technologies

## Test results

- + Results show a significant increase in bending strength for each joint concept design.
- + Internal pressure tests are still pending...



Failure after bending type test: reference design (left), longitudinal bolt design (right)

# 5. Conclusion and Next Steps



- Effective approaches could be identified to upgrade ReCoTec® composite hollow core insulators for future application with alternative insulation gases.
- A thermoplastic film liner on the inside of the GFRP tube works well as an additional diffusion barrier and shows good chemical resistance against gas decomposition products like HF.
- New joining technology concepts of flange and tube show a promising performance at the bending type test. Pending internal pressure type tests will help with identification of the best flange-tube joint concept.
- A test insulator with a TP film liner and new flange-tube joint technology would still need to be subjected to a long-term tightness test to check if leakage rate requirements can be fulfilled.

## 6. References

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- [2] N. N.: Regulation (EU) 2024/573 of the European Parliament and of the Council of 7 February 2024 on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014, Official Journal of the European Union, Series L, Document 32024R0573, 2024
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- [8] CIGRE WG B3.45: CIGRE TB 802 – Application of non-SF<sub>6</sub> gases or gas-mixtures in medium and high voltage gas-insulated switchgear, 2020
- [9] IEC 61462:2023, Composite hollow insulators – Pressurized and unpressurized insulators for use in electrical equipment with AC rated voltage greater than 1000 V AC and D.C. voltage greater than 1500 V – Definitions, test methods, acceptance criteria and design recommendations



# Thank you for your interest.

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