

## Qualification of the SuperRail HTS cable system

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# Content

- I. Motivation of the SuperRail project
- II. Qualification of the SuperRail HTS cable system
  - Type test loop
  - Type test results
- III. Conclusion

# I. Motivation

# Motivation

Need to increase rail traffic in densely populated areas  
to meet carbon emission reduction targets by 2030

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Need to increase the electric power



## Practical case

Reinforcement of Paris Montparnasse train station

28 tracks, 200 000 passengers/day on 750 trains

50 Millions of passengers in 2020, 90 Millions in 2030

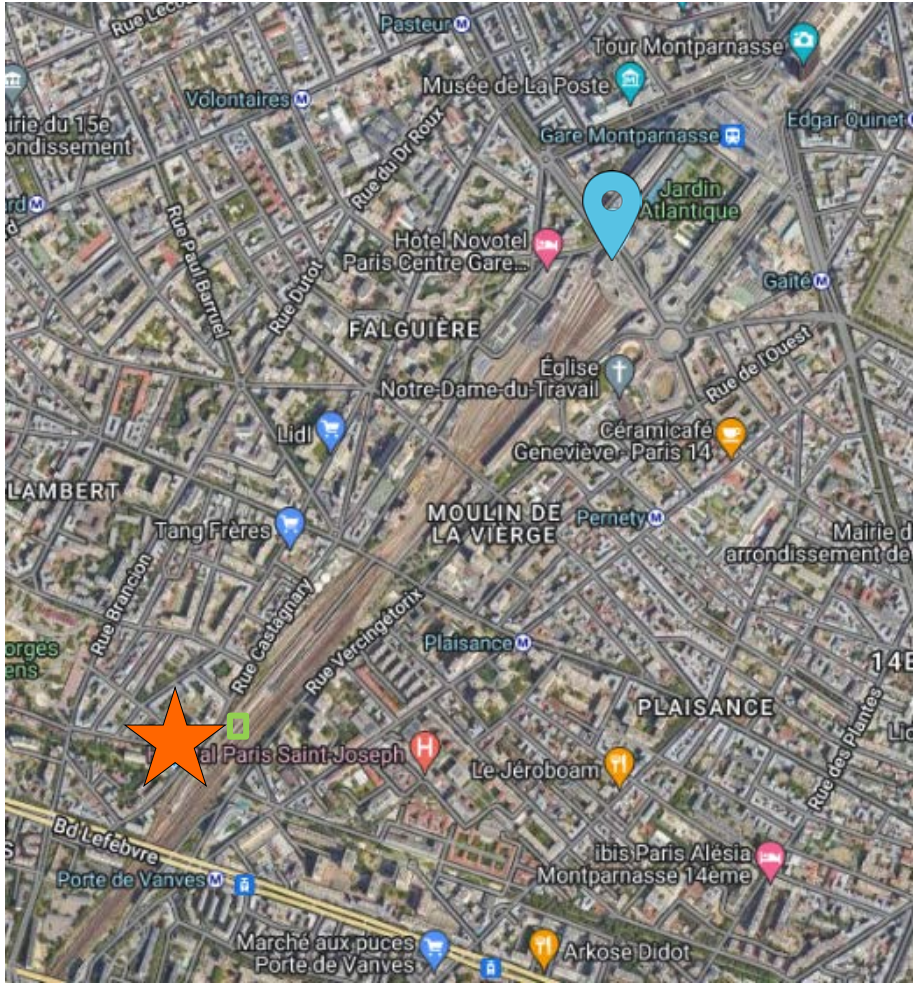


4.5 MW of nominal power (3000 A @1500 VDC)

10.5 MW of inrush power (7000 A)

Fault current of 67 kA during 100 ms

# Practical case



Paris Montparnasse



Substation



Tracks

## Practical case



Existing rights of way saturated  
 only  $2 \times \Phi 100$  mm conduit left  
 =  $2 \times 400$  mm<sup>2</sup> copper cable  
 =  $2 \times 500$  A reinforcement

Instead of the required 3000 A

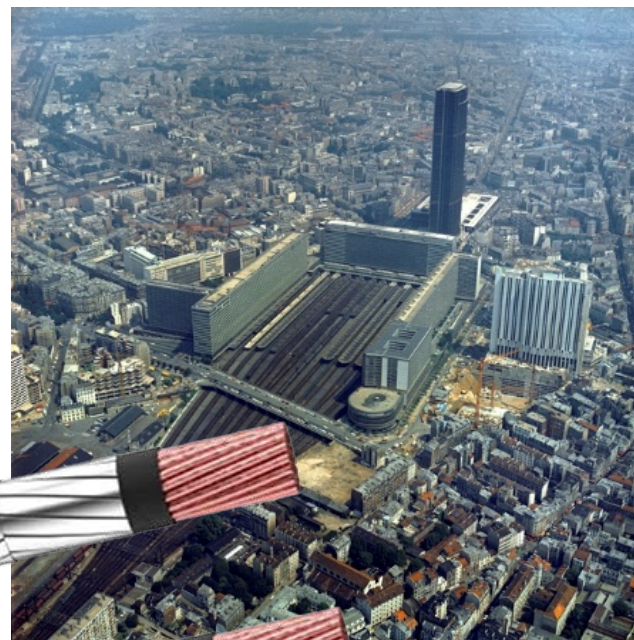


Limited available space  
 & other networks (water, gas, telecom)  
 & century-old civil engineering structures

Very risky, expensive and time-consuming  
 to build new rights of way

# SuperRail

Paris, France

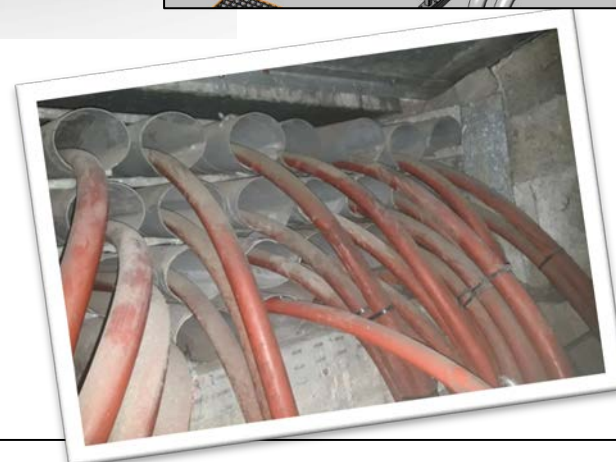
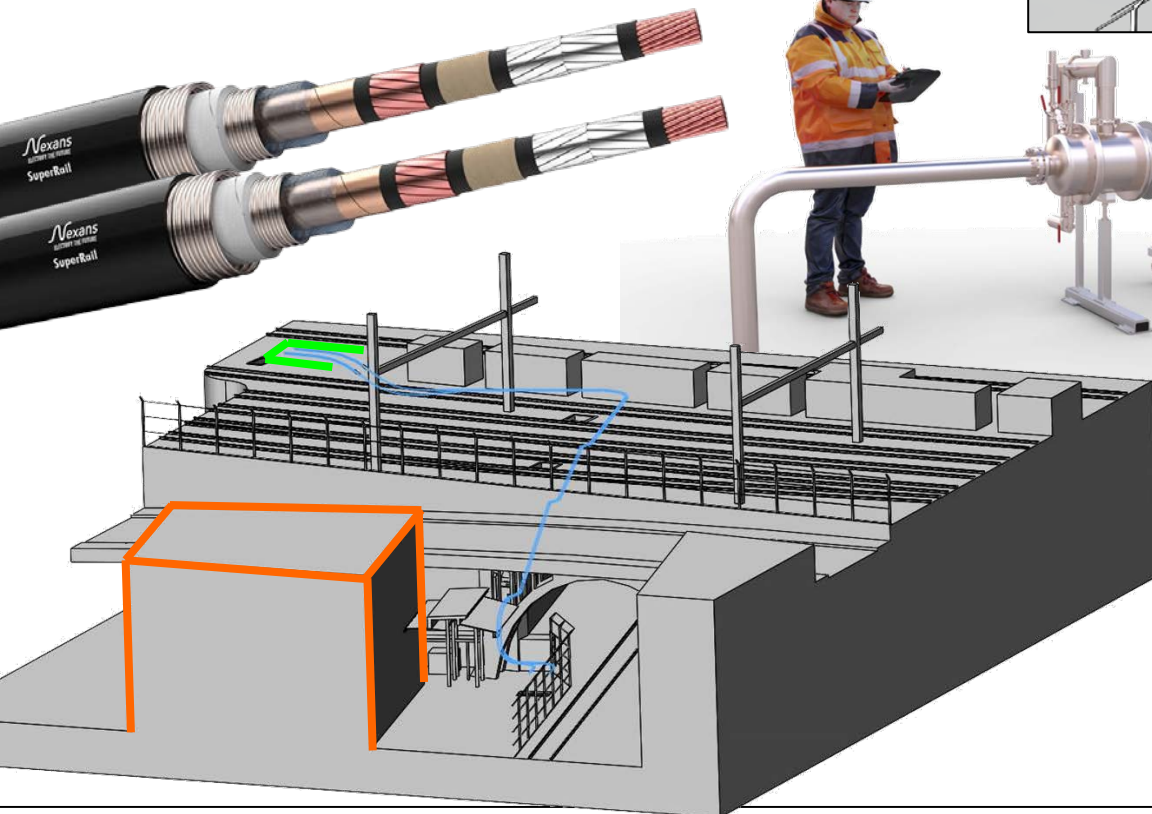
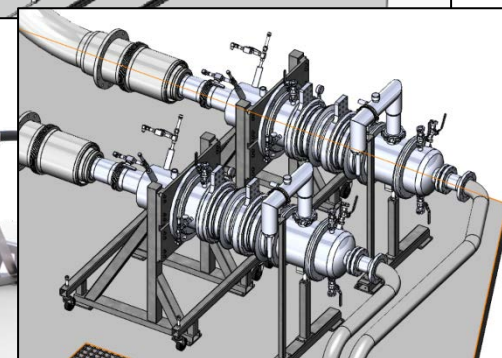
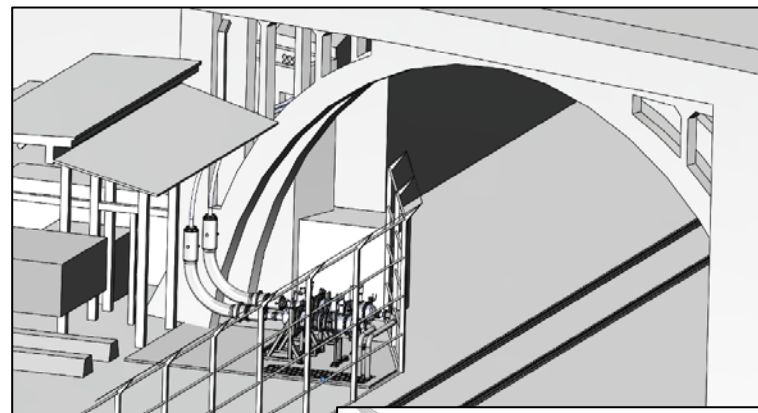




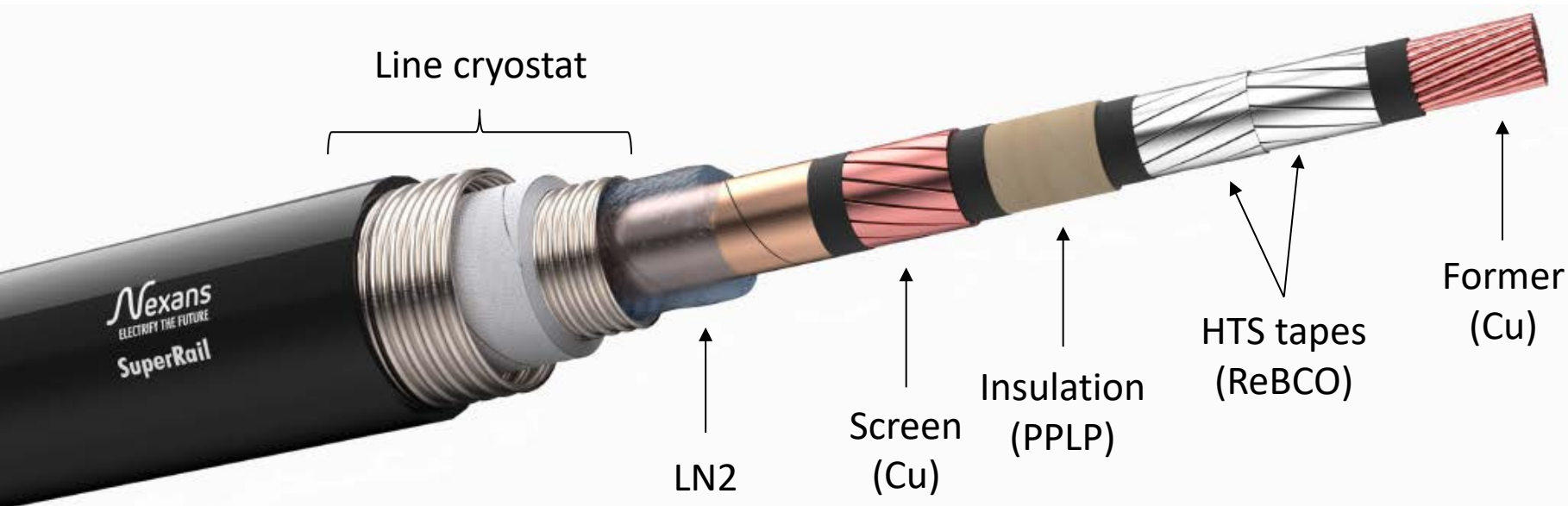
# Integration

- Installation in existing conduits
- Sharp gradient and turns
- Continuous operation

Substation side



# Superconducting cable



Electric parameters	
Nominal voltage	1500 V
Nominal current	1500 A
Inrush current	3500 A
Critical current	>4000 A
Fault current	67 kA - 100 ms

Geometric parameters	
Cryostat outer diameter	74 mm
Minimum bending radius	1.5 m
Length	2x 60 m

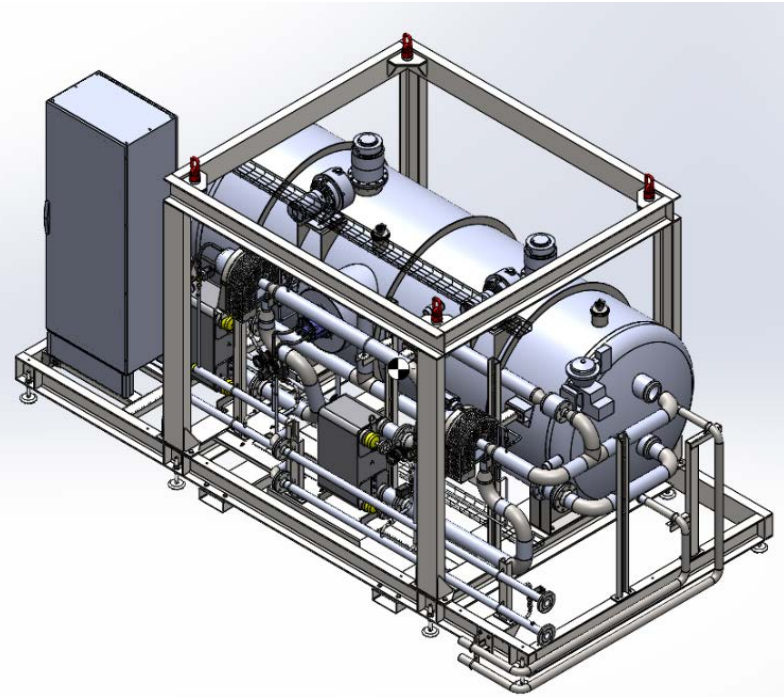
# Cooling system



## Cryogenic skid

- ▶ For type test & for final installation
- ▶ LN2 circulation & pressurization
- ▶ Cool down and warm up management (requires a LN2 tank)

+



## Reverse Turbo Brayton (RTB)

- ▶ Only for the final installation
- ▶ Newly developed cooling system with high efficiency and low maintenance
- ▶ 1.7 kW @67 K

## II. Qualification of the SuperRail cable system

### Type test loop

# SNCF Railway Test Agency (SNCF-AEF)



SNCF-AEF Traction substation



SNCF-AEF Electrotechnics laboratory

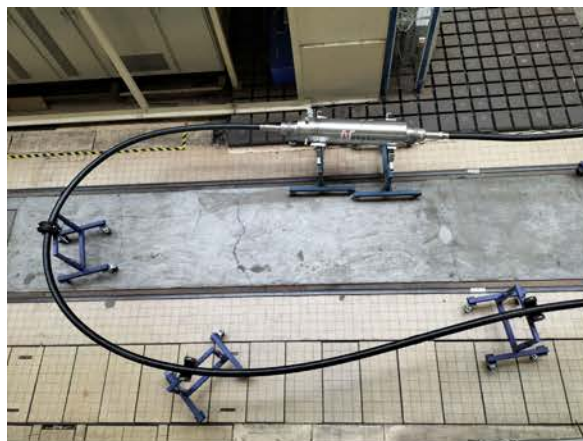
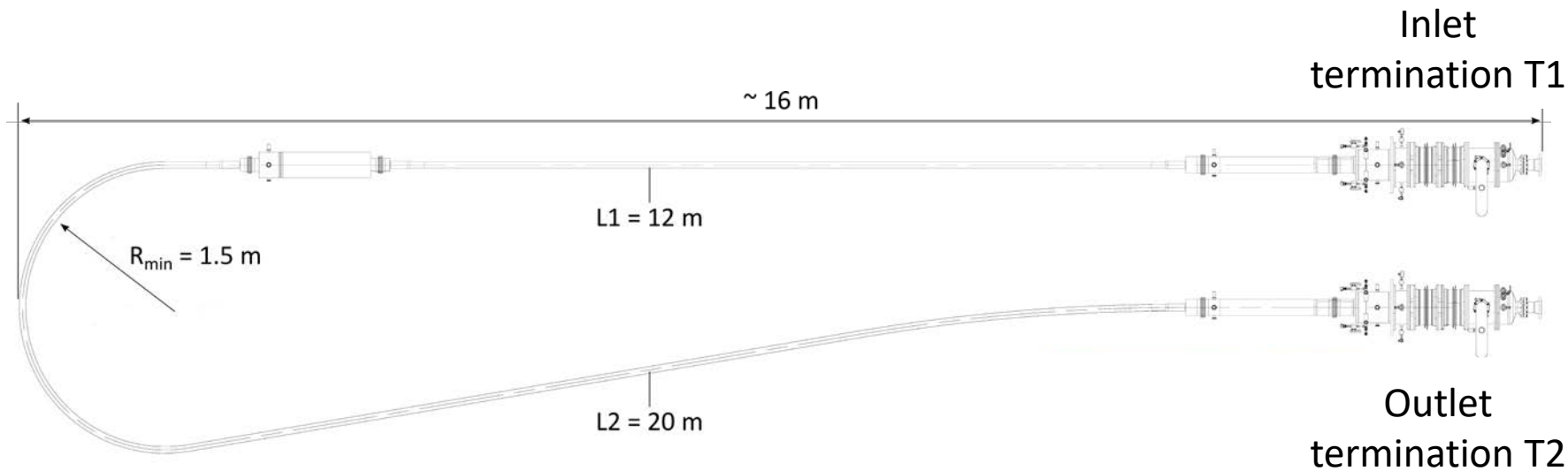


## Type test loop

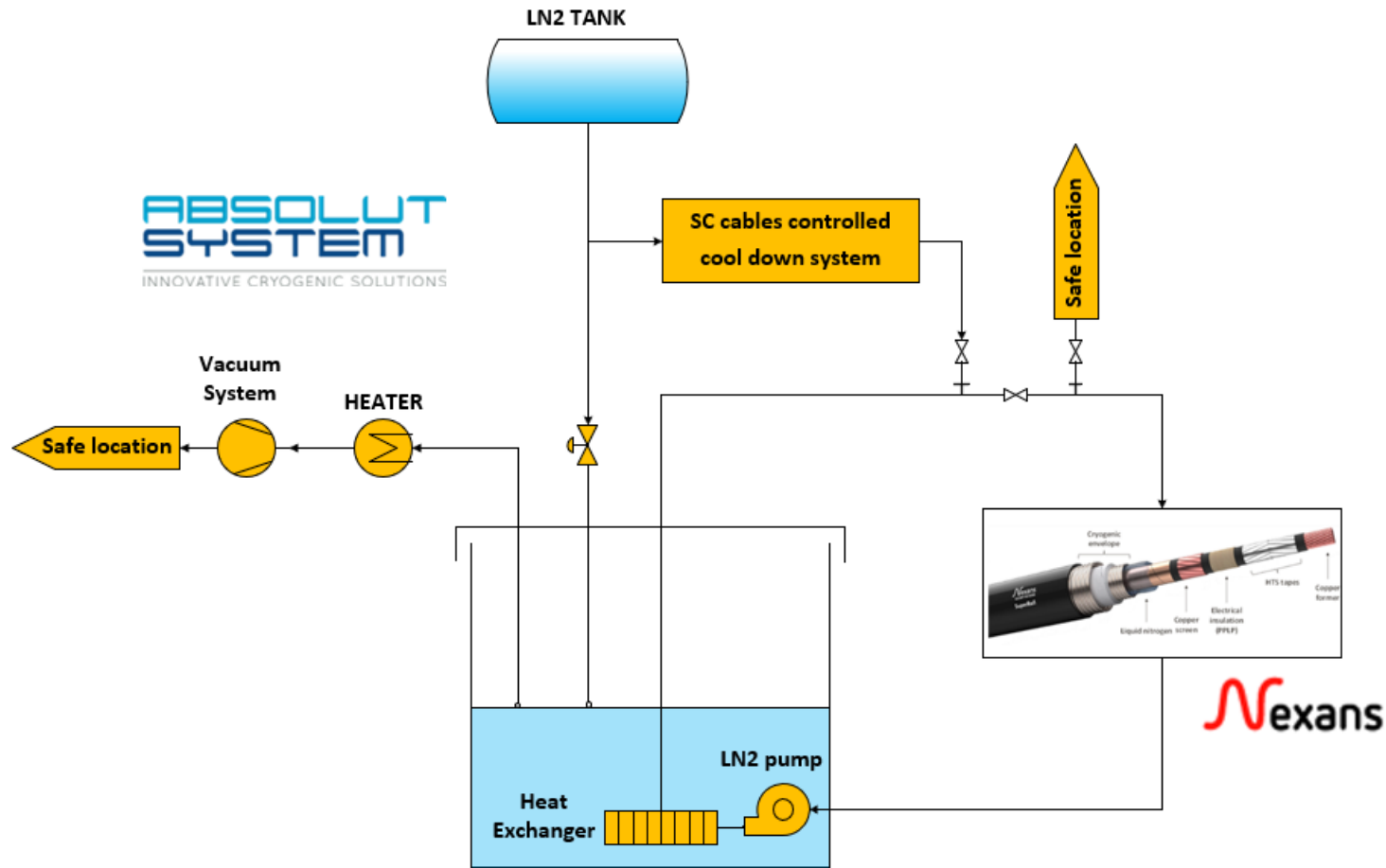
- ▶ 32 m test loop
  - ▶ 2 cable pieces
  - ▶ 2 terminations
  - ▶ 1 joint
- ▶ LN2 tank
- ▶ LN2 circulation SKID
- ▶ Controlled cool down system



# Type test loop

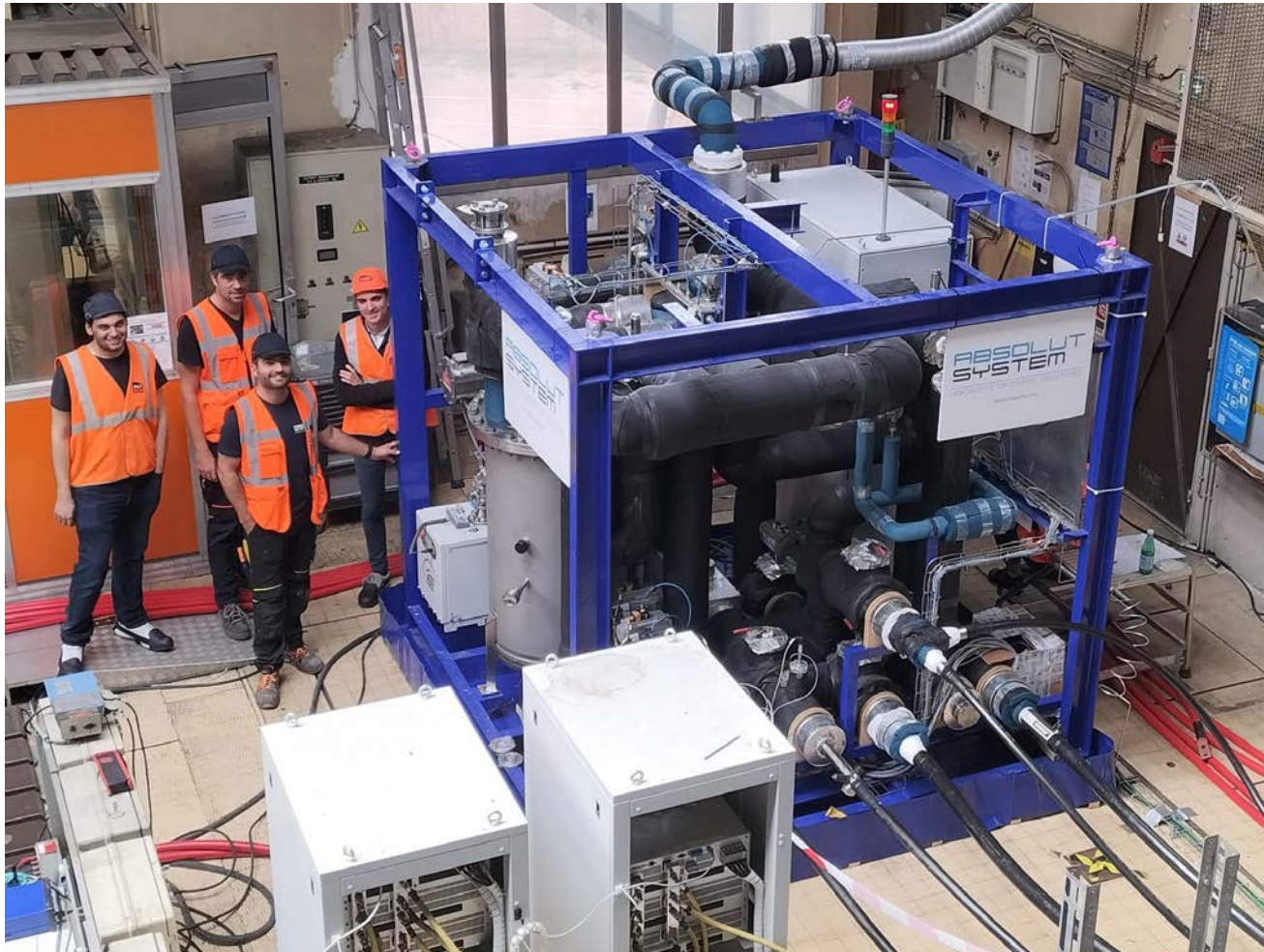


# Type test loop





# Type test loop



# Type test loop



LN2  
circulation  
SKID

Controlled  
cool down  
system

Inlet  
termination  
T1

Outlet  
termination  
T2



## **II. Qualification of the SuperRail cable system**

### **Type test results**

# Timeline

## August 2023 Tests at SNCF AEF #1

- Thermal cycles
- Pressure
- Dielectric & lightning impulse
- Nominal current

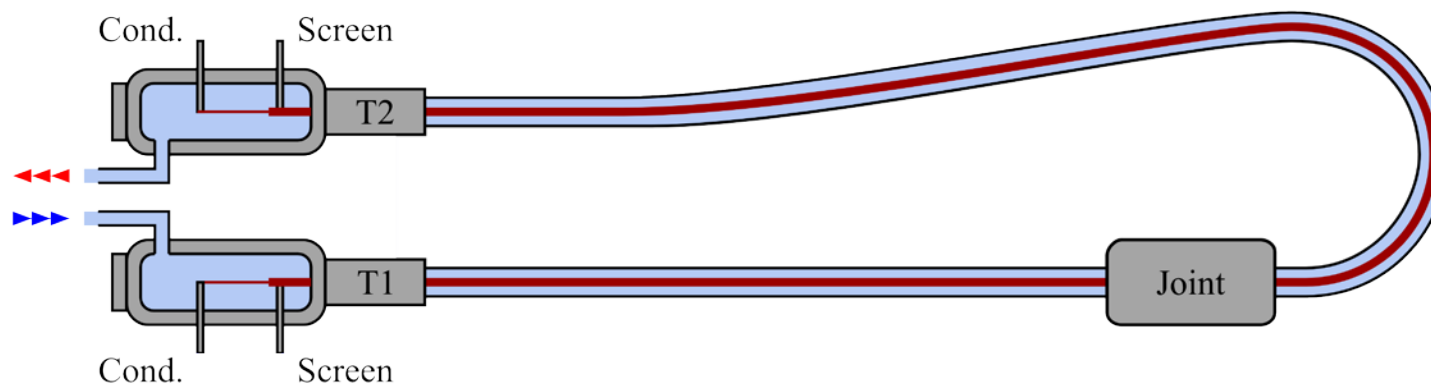
## April 2024 Tests at SNCF AEF #2

- Nominal current
- System losses & pressure drop
- Fault current & recovery time
- V-I characterization

### Applicable standards:

- IEC 63075:2019 specifies test methods and requirements for HTS AC power cable systems (cables and their accessories) for fixed installations, for rated voltages from 6 kV up to 500 kV.
- EN 50124-1, EN 60664-1, EN 50124-1 are electrical standards specific to railway grids.

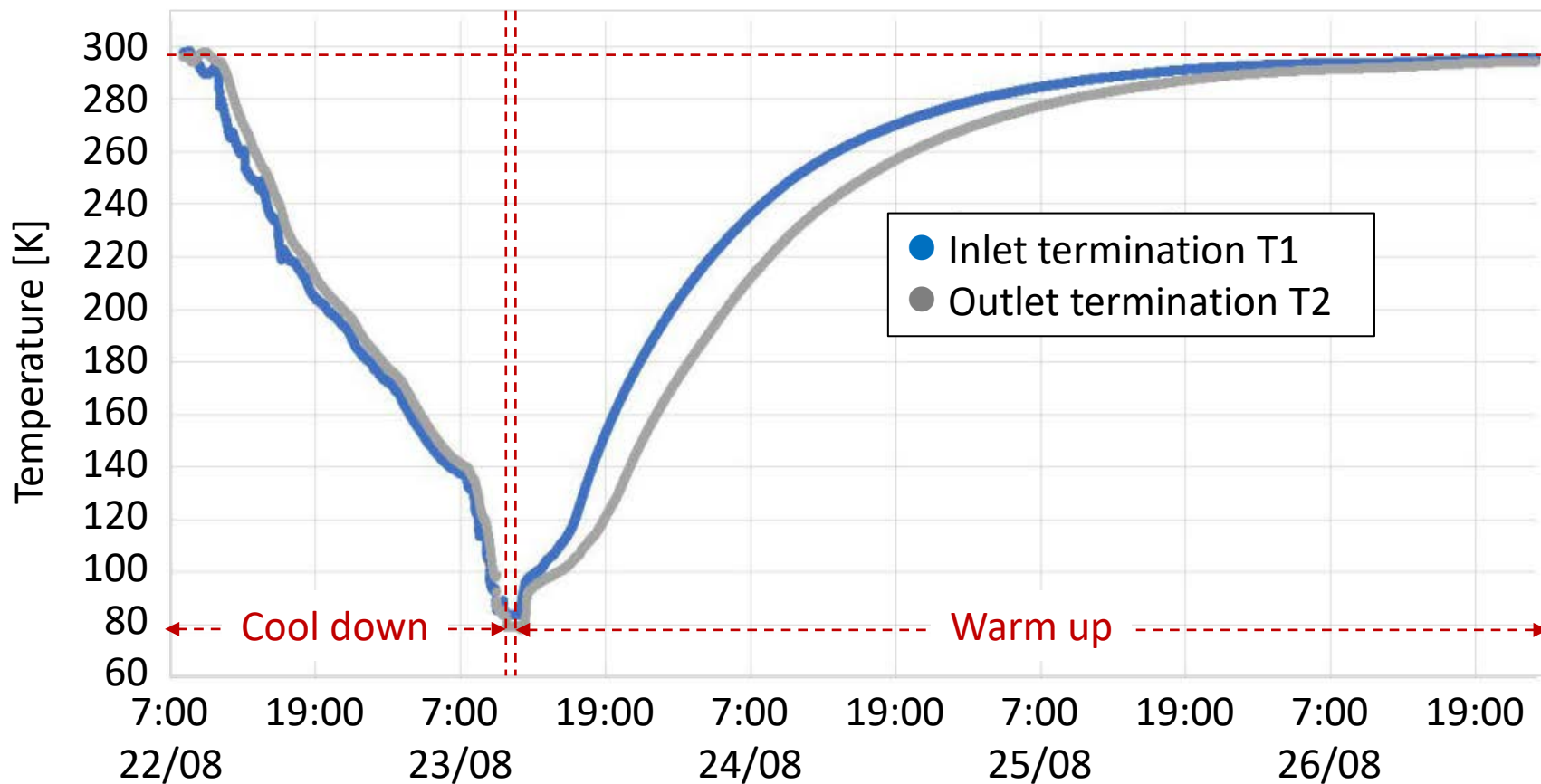
# Thermal cycles



- 5 cycles of cooling down and warming up

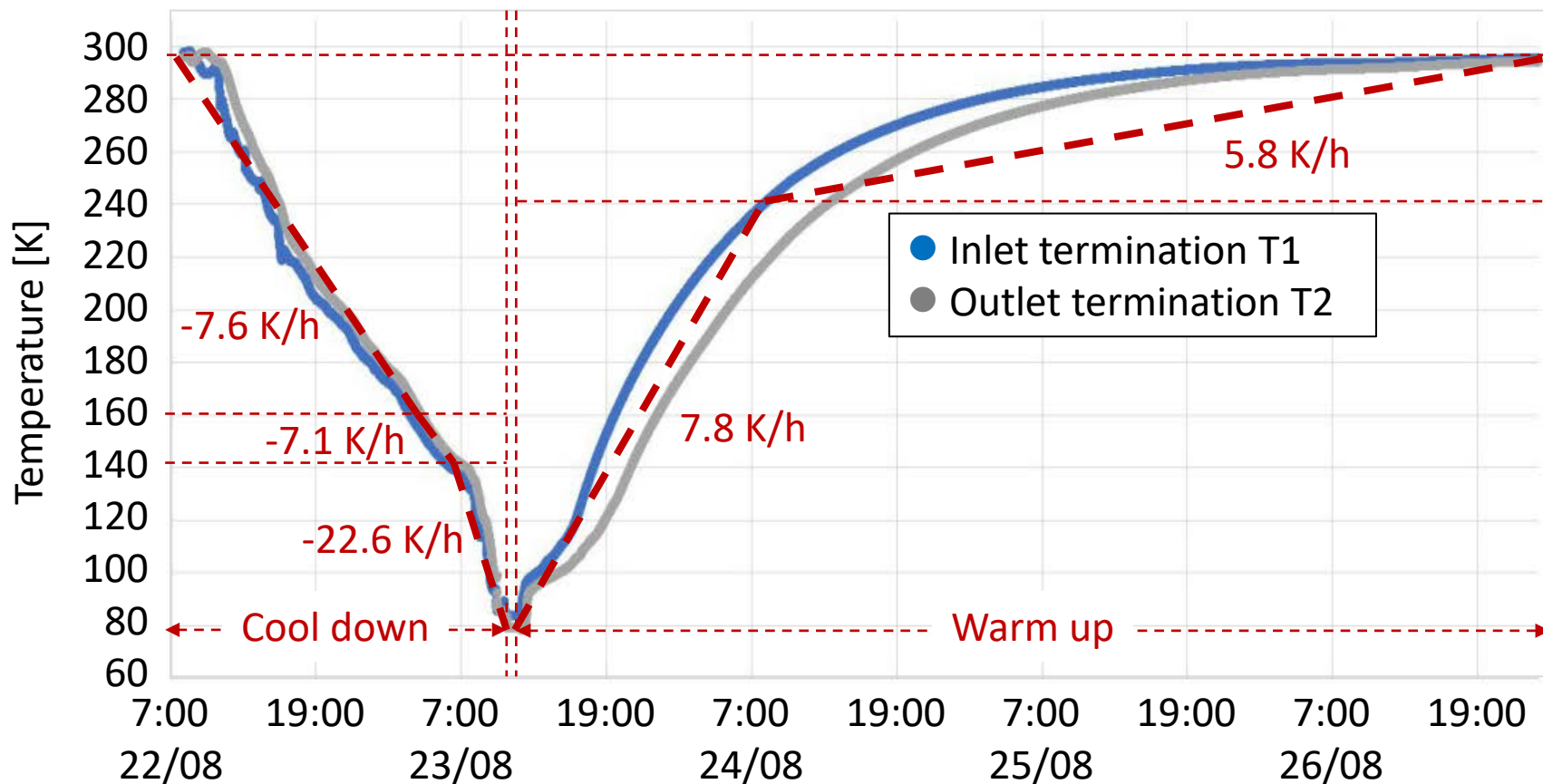
# Thermal cycles

Manual cooling down and warming up: thermal cycle 4



# Thermal cycles

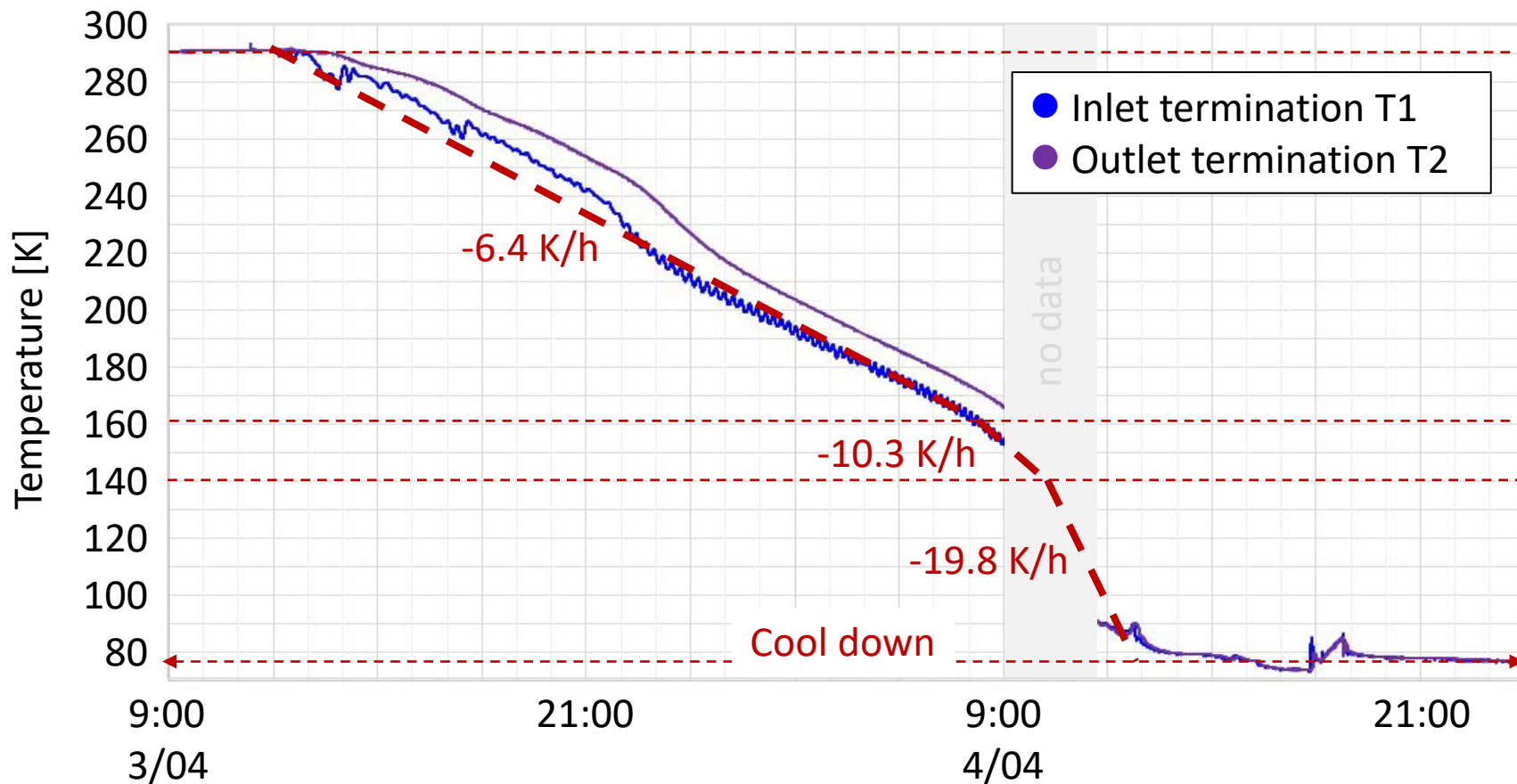
Manual cooling down and warming up: thermal cycle 4



- Thermo-mechanical robustness of the system fully validated ✓

# Thermal cycles

Automatic cooling down: thermal cycle 6



- Automatic cool down validated
- No risk for Montparnasse Vouillé system (cooling rate < 10 K/h) ✓



# Pressure

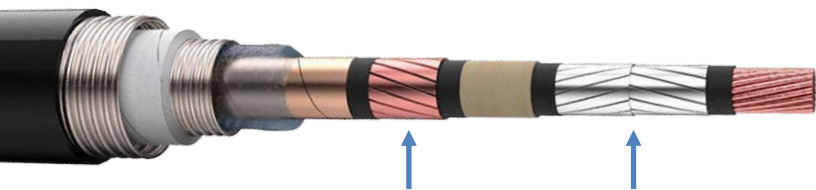
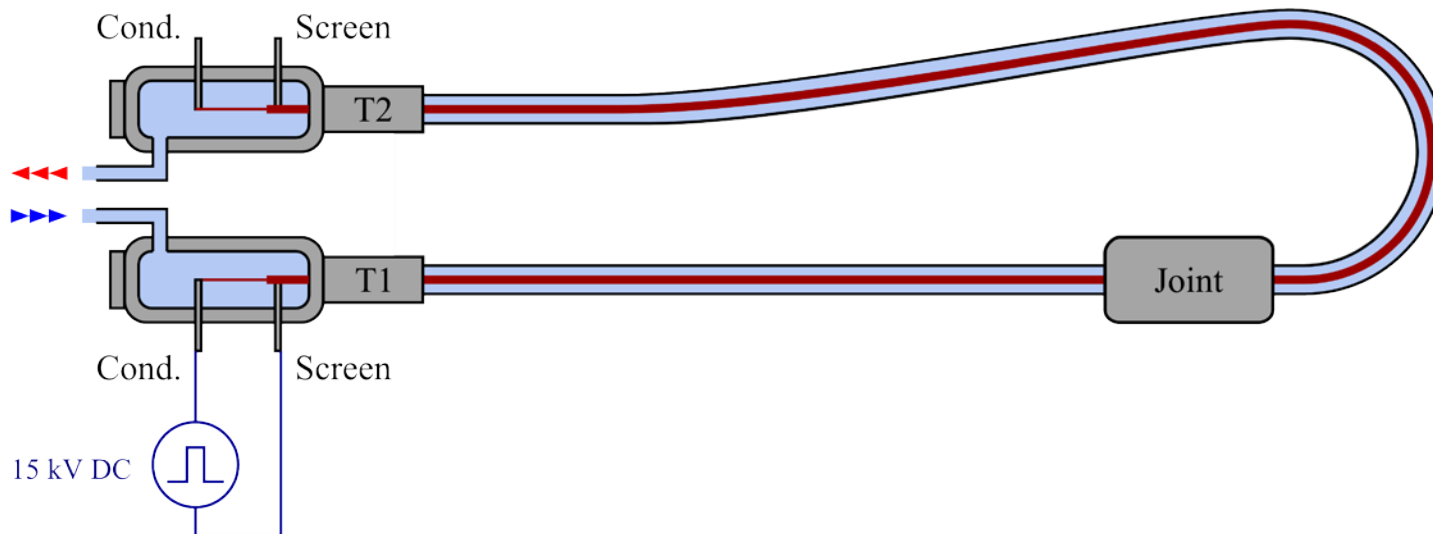
Immediately after assembly: successful pressure test up to 18.5 bar to validate the system's safety devices.

During tests with LN2 pressurized loop:

- 12 bar operating pressure during several hours
- 15 bar max peak value (up to safety valves opening)
- In line with the operational pressure at Montparnasse Vouillé ✓

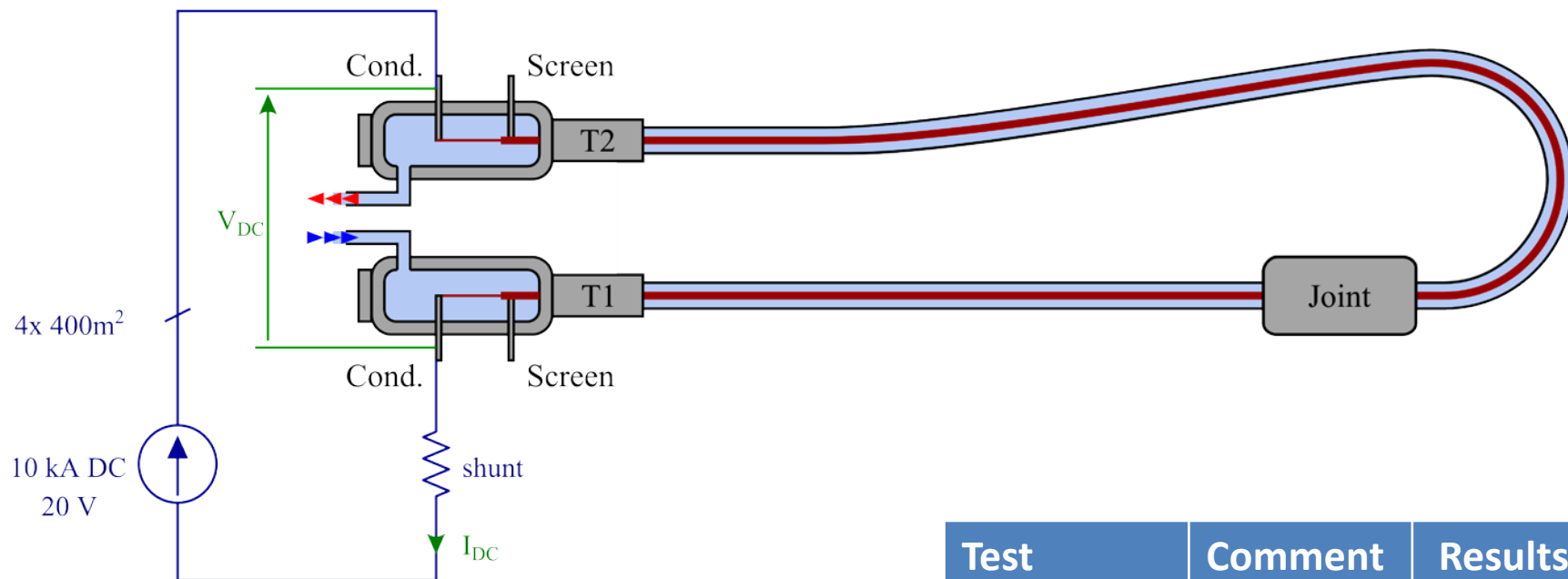


# Dielectric & Lightning impulse



Test	Comment	Results
Dielectric	1.5 kV DC class 10 kV DC / 10 s	✓
Lightning impulse	1.5 kV DC class 3× ±15 kV shots	✓

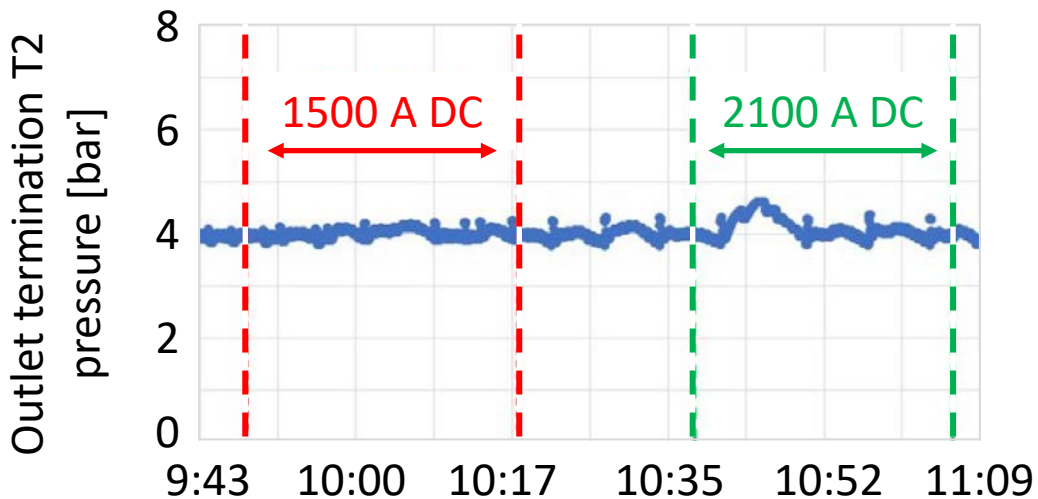
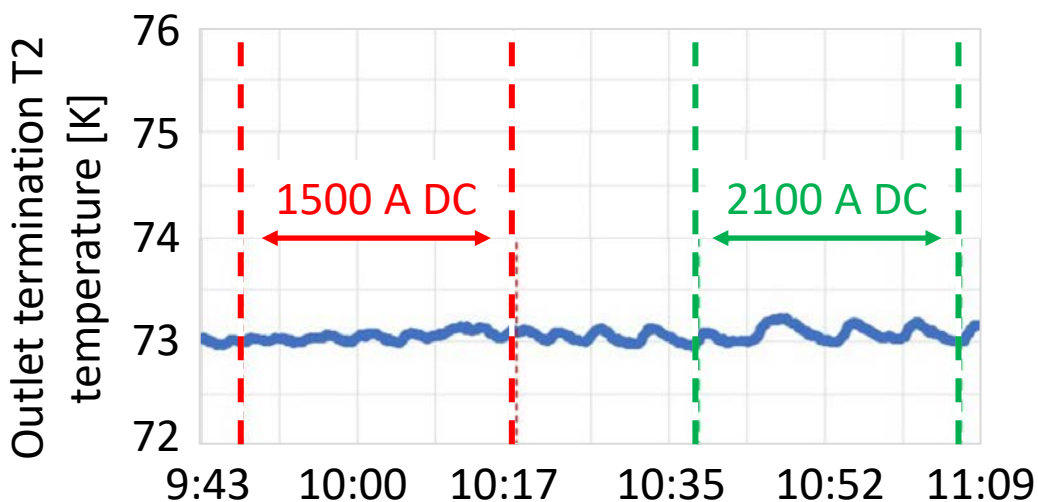
# Nominal current



Test	Comment	Results
1500 A DC	30 min	✓
2100 A DC	30 min	✓

# Nominal current

- No significant temperature or pressure increase
- Stabilization over time
- No resistance increase of the loop
- Integrity of the system unchanged after test
- Continuous current up to 2 kA is “transparent” for Montparnasse Vouillé operation. ✓

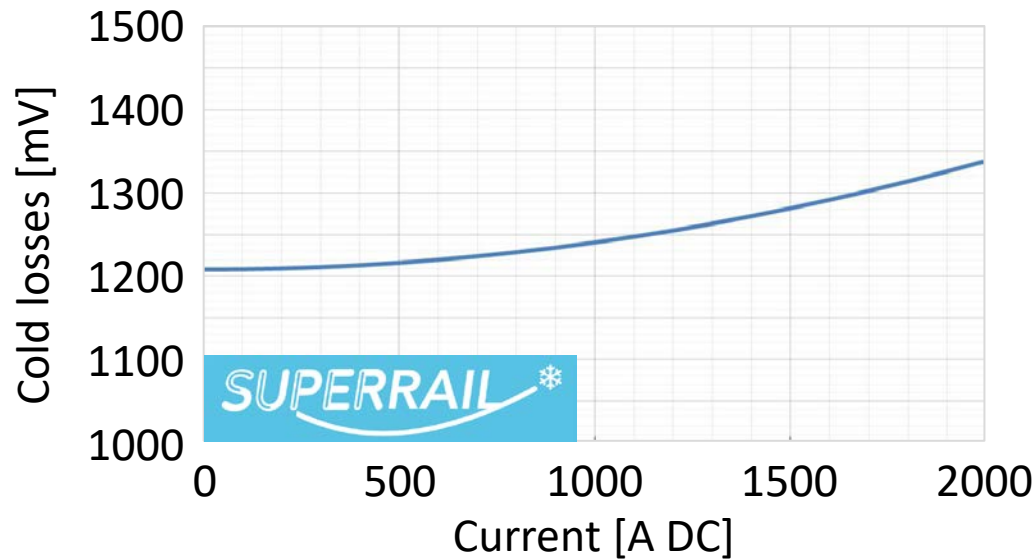


# System losses & pressure drop

Measured cold losses : ~561 W without current

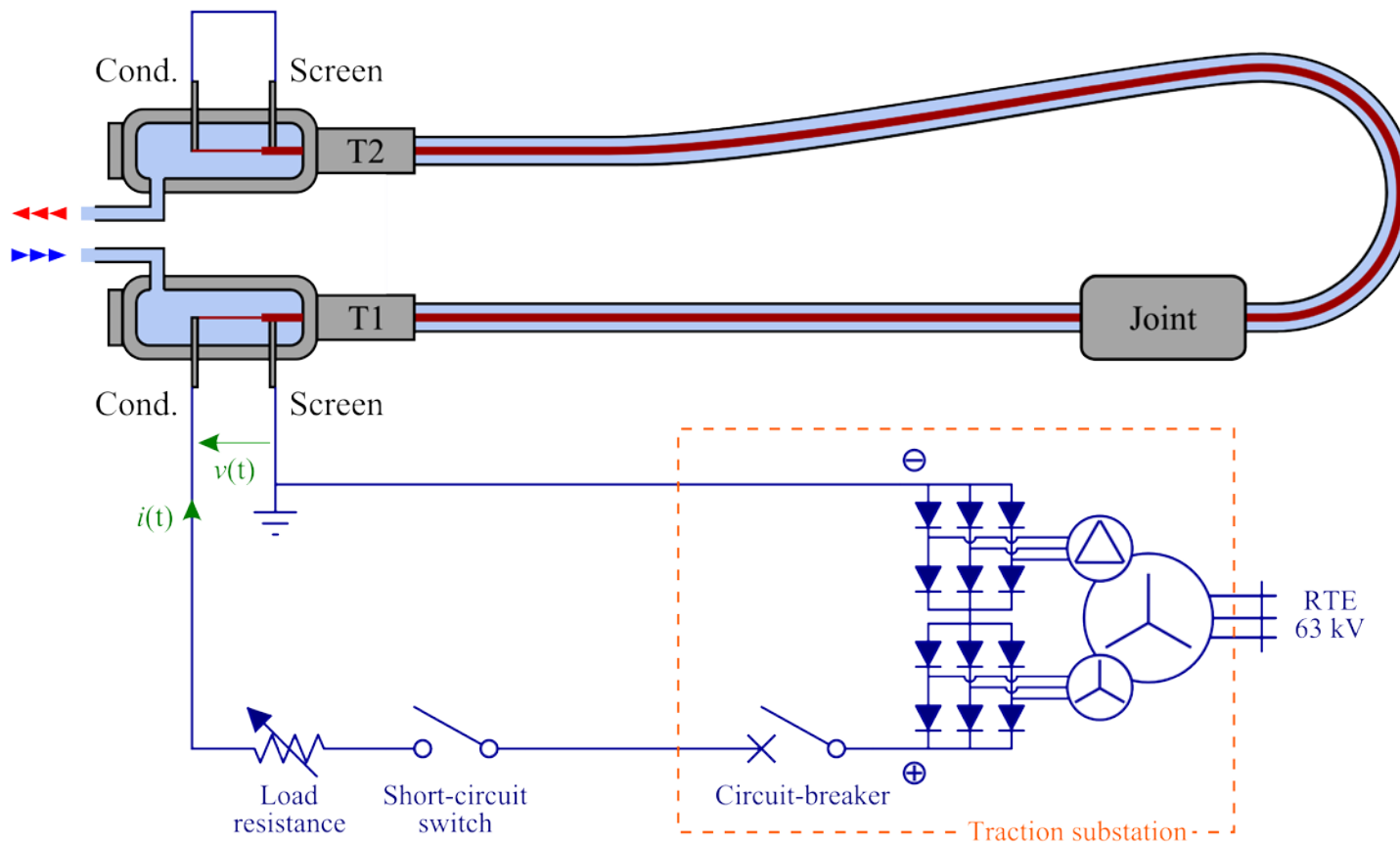
Loss model validated ✓

Update the estimated cold losses at Montparnasse Vouillé :

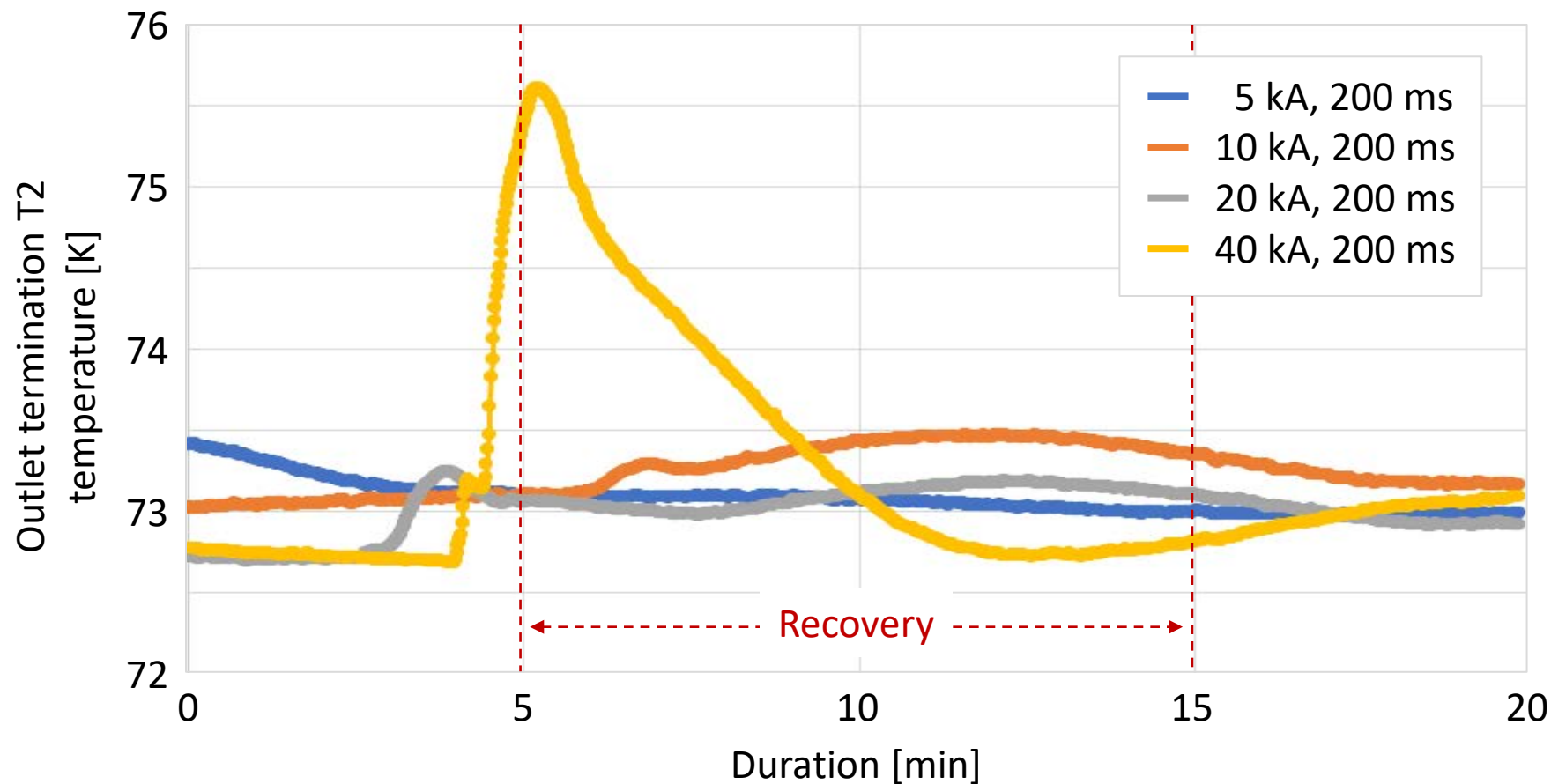


- In line with cooling capacity planned for Montparnasse Vouillé ✓

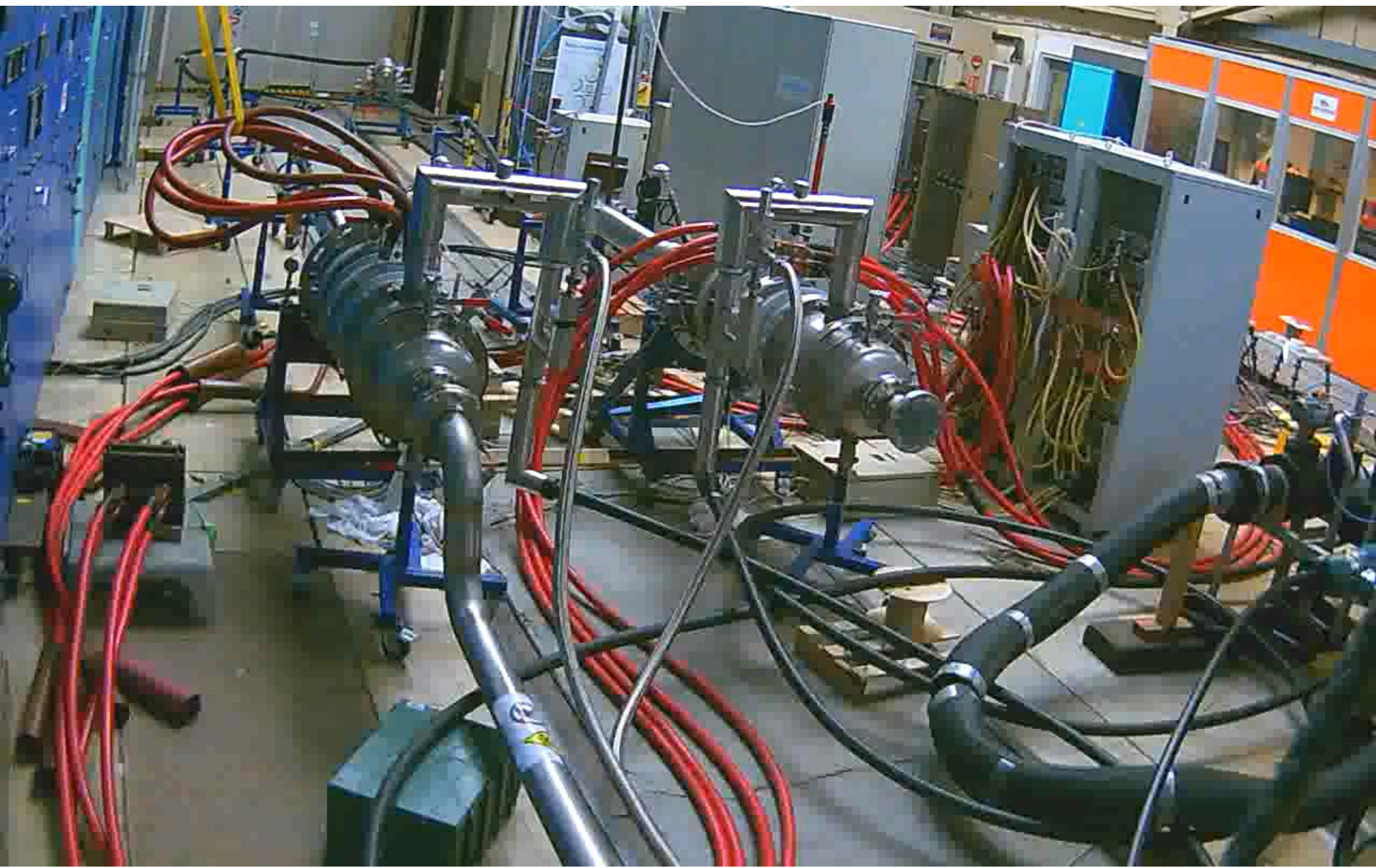
# Fault current & recovery time



# Fault current & recovery time

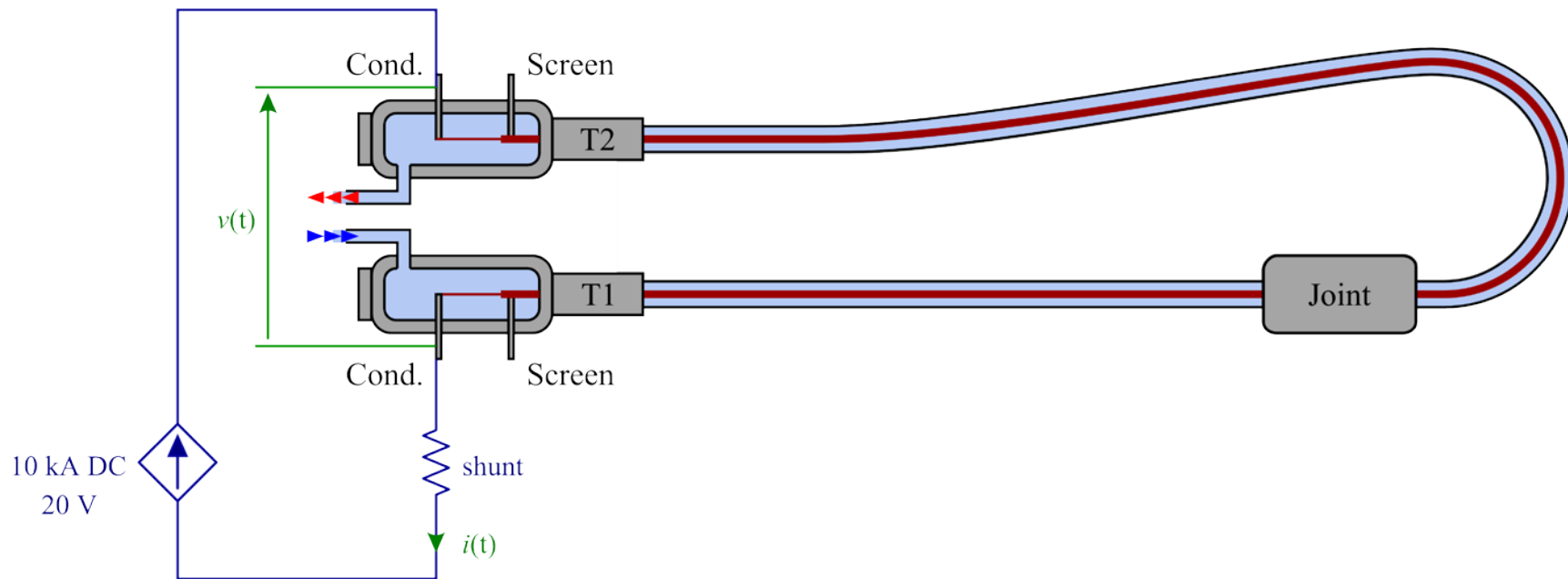


- No resistance increase of the loop
- Integrity of the system unchanged after test ✓



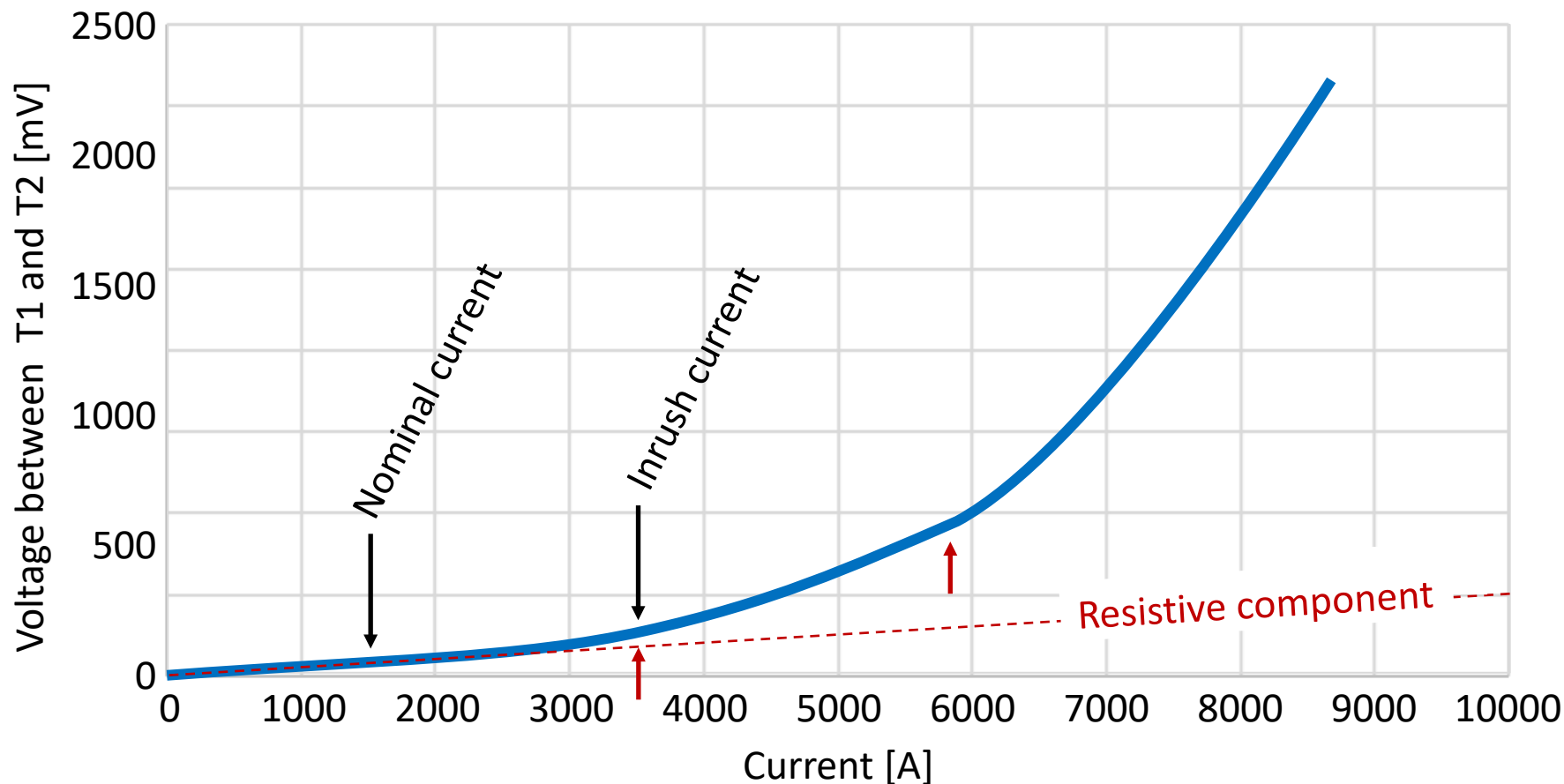


# V-I characteristic



# V-I characteristic

$I_c > 4000$  A ✓



- No degradation of  $I_c$  after all the tests (including fault current ! ) ✓
- High robustness of the SuperRail cable system ✓

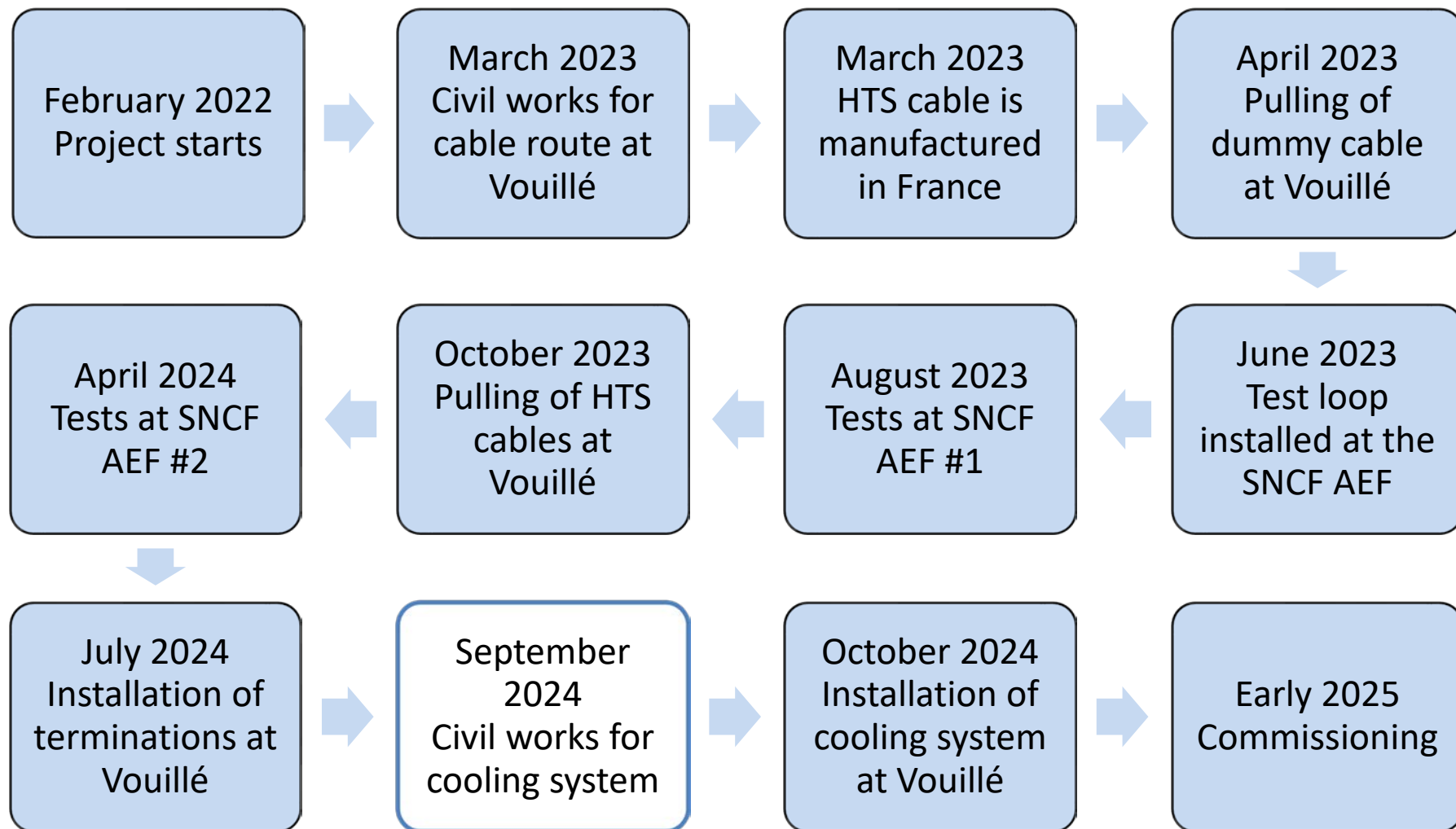
# Conclusion

# Summary of type test at SNCF AEF



Test	Results
Thermal cycles	✓
Pressure	✓
Dielectric	✓
Lightning impulse	✓
Nominal current	✓
System losses & pressure drop	✓
Fault current & recovery time	✓
V-I characteristic	✓

# Timeline of the full project



# SUPERRAIL



# References

- [1] A. Allais, J.-M. Saugrain, B. West, N. Lallouet, H. Caron, L. Terrien, G. Bouvier, K. Berger, L. Quéval, “SuperRail – World-first HTS cable to be installed on a commercial railway network in France,” *IEEE Transactions on Applied Superconductivity*, vol. 34, no. 3, pp. 1-7, May. 2024. ([DOI](#), [link](#))
- [2] NF EN 50124-1, “Applications ferroviaires – Coordination de l’isolement,” version de juin 2017.
- [3] NF EN 60664-1, “Coordination de l’isolement des matériels dans les systèmes (réseaux) à basse tension. Partie 1 : Principes, exigences et essais,” version de juillet 2020.
- [4] CEI 63075, “Câbles supraconducteurs d'alimentation en courant alternatif et leurs accessoires pour des tensions assignées de 6 kV à 500 kV. Méthodes d'essai et exigences,” Version de février 2019.

# Applicable standards

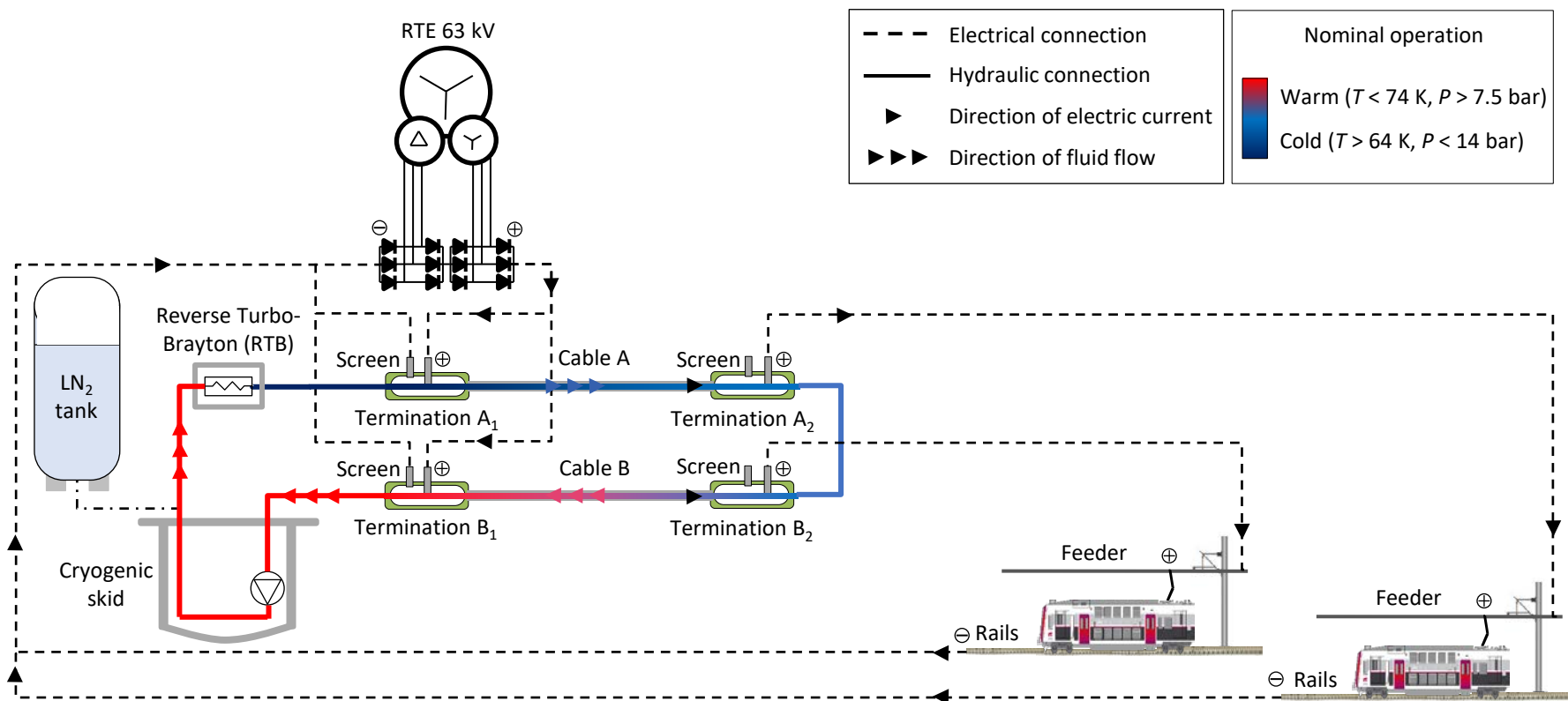
Test	Applicable standard	Description
Bending test	IEC 63075*	3 bends of 180° repeated in both directions + visual inspection
Ic measurement	IEC 63075*	Check any Ic degradation on tapes after bending
Pressure test	IEC 63075	1.1x max operating pressure After installation, prior to cool down, without safety devices
Thermal test	IEC 63075	5 cycles of cooling down and warming up
Lightning impulse	EN 50124-1** Table A2 EN 60664-1** (only for 1.5 kV)	$U_n = 1.5 \text{ kV}$ $U_{Nm} = 1.8 \text{ kV}$ $U_{Ni} = 15 \text{ kV (OV4)}$ $U_n = 3 \text{ kV}$ $U_{Nm} = 3.6 \text{ kV}$ $U_{Ni} = 30 \text{ kV (OV4)}$ page 18 : 3x 1.2 $\mu\text{s}/50 \mu\text{s}$ each polarity
Dielectric test	EN 50124-1** Table B1	$U_{Ni} = 15 \text{ kV}$ $U_a = 6.9 \text{ kVrms} / 10 \text{ kVDC}$ $U_{Ni} = 30 \text{ kV}$ $U_a = 14 \text{ kVrms} / 20 \text{ kVDC}$
Fault current	No specific standard	Energy equivalent to 67 kV - 200 ms fault with terminations temperature monitoring until recovery

\* IEC 63075:2019 specifies test methods and requirements for HTS AC power cable systems (cables and their accessories) for fixed installations, for rated voltages from 6 kV ( $U_m = 7.2 \text{ kV}$ ) up to and including 500 kV ( $U_m = 550 \text{ kV}$ ).

\*\* Electrical standards specific to railway networks.



# SuperRail commercial demonstrator



A. Allais, J.-M. Saugrain, B. West, N. Lallouet, H. Caron, L. Terrien, G. Bouvier, K. Berger, L. Quéval, "SuperRail – World-first HTS cable to be installed on a commercial railway network in France," *IEEE Transactions on Applied Superconductivity*, vol. 34, no. 3, pp. 1-7, May. 2024. ([DOI](#), [link](#))



# Technology Readiness Levels

- TRL 0: Idea.** Unproven concept, no testing has been performed.
- TRL 1: Basic research.** Principles postulated and observed but no experimental proof available.
- TRL 2: Technology formulation.** Concept and application have been formulated.
- TRL 3: Applied research.** First laboratory tests completed; proof of concept.
- TRL 4: Small scale prototype** built in a laboratory environment ("ugly" prototype).
- TRL 5: Large scale prototype** tested in intended environment.
- TRL 6: Prototype system** tested in intended environment close to expected performance.
- TRL 7: Demonstration system** operating in operational environment at pre-commercial scale.
- TRL 8: First of a kind commercial system.** Manufacturing issues solved.
- TRL 9: Full commercial application,** technology available for consumers.

DC

AC