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SupernetNL program: 3.4 km 110 kV AC underground superconducting cable in the Dutch grid

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IWC-HTS Karlsruhe, June 14-15, 2017

Consortium

Transmission System Operator

High-Voltage issues and superconductor: cable isolation and connections

System aspects (thermal/reliability)

TenneT Taking power further

TUDelft Delft University of Technology

IWO

Hogeschool van Arnhem en Nijmegen
HAN University of Applied Sciences

RH MARINE GROUP

UNIVERSITY OF TWENTE.

Instrumentation and monitoring

System aspects

Thermal aspects, cryogenics and superconductor

Outline

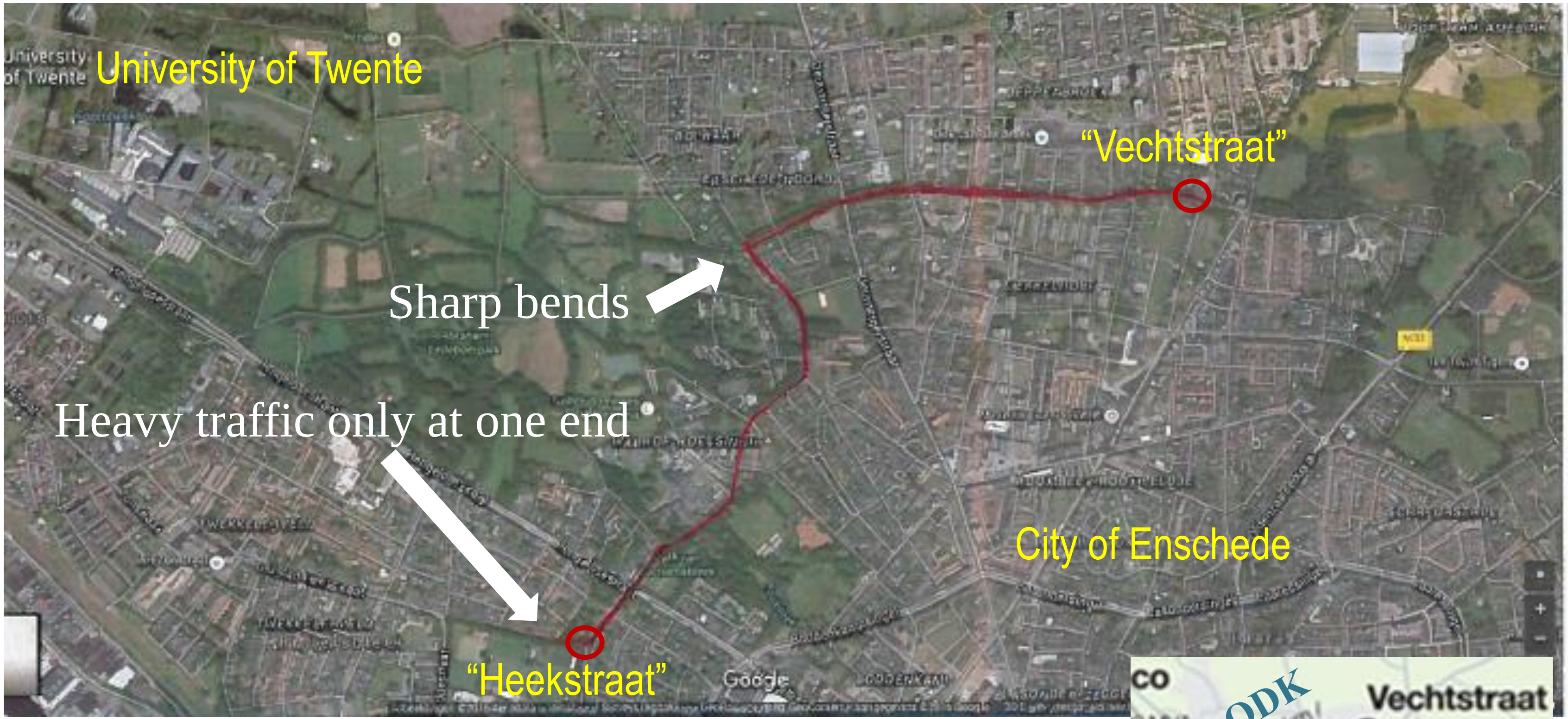
- Objectives

- Cable type and heat loads?
- What temperature?
- Cooling system?
- Cable geometries and cooling stations?
- Cool-down time?
- Shrinkage?

- Status and planning

Disclaimer: we are not cable designers, we advise TenneT specifcally on cryogenic issues

Objectives



HTS superconducting cable
110 kV, 3.4 km
Applied in the grid (full TRL)
Operational in 2019

Objectives

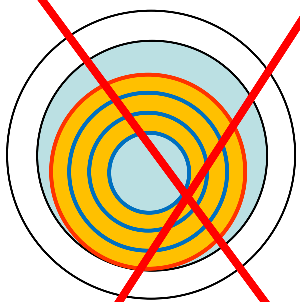
Voltage	110 kV AC
Transport capacity	150 MVA
Max earth fault current	1 sec: 30 kA
Max 3-phase short current	1 sec: 40 kA
Length	3,4 km
Life time	40 years
Outage time	2 -3 weeks

Data from TenneT set of specifications

Contact: Shima Mousavi Gargari: shima.mousavi.gargari@tennet.eu

Cable type and heat load

~~HTS Triax®~~

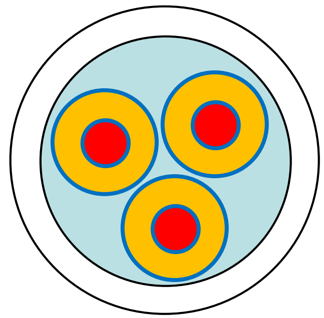


~~Good for 10-72 kV~~

~~+ Uses less material~~

~~- Complex manufacturing~~

3-in-one



Good for 10-138 kV

+ Large copper shunt

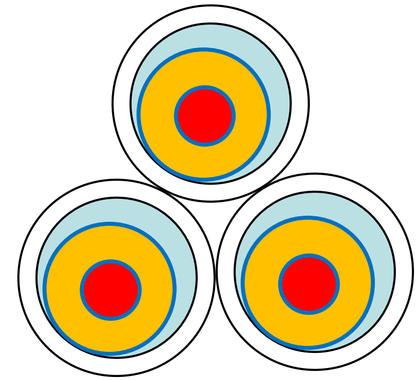
- Needs a separate return cryostat

AC loss: 3 x (0.5 – 1) W/m
Heat leak: 2 W/m plus return (1W/m)

Total ca 5 W/m
3,4 km: 17 kW

3 X 1

In three separate cryostats



Good for 72 – 275 kV

+ Simple manufacturing

- Uses more material

AC loss: 3 x (0.5 – 1) W/m
Heat leak: 3 x 1 W/m

Total ca 5 W/m
3,4 km: 17 kW

➡ Required cooling power will not make the difference

What temperature?

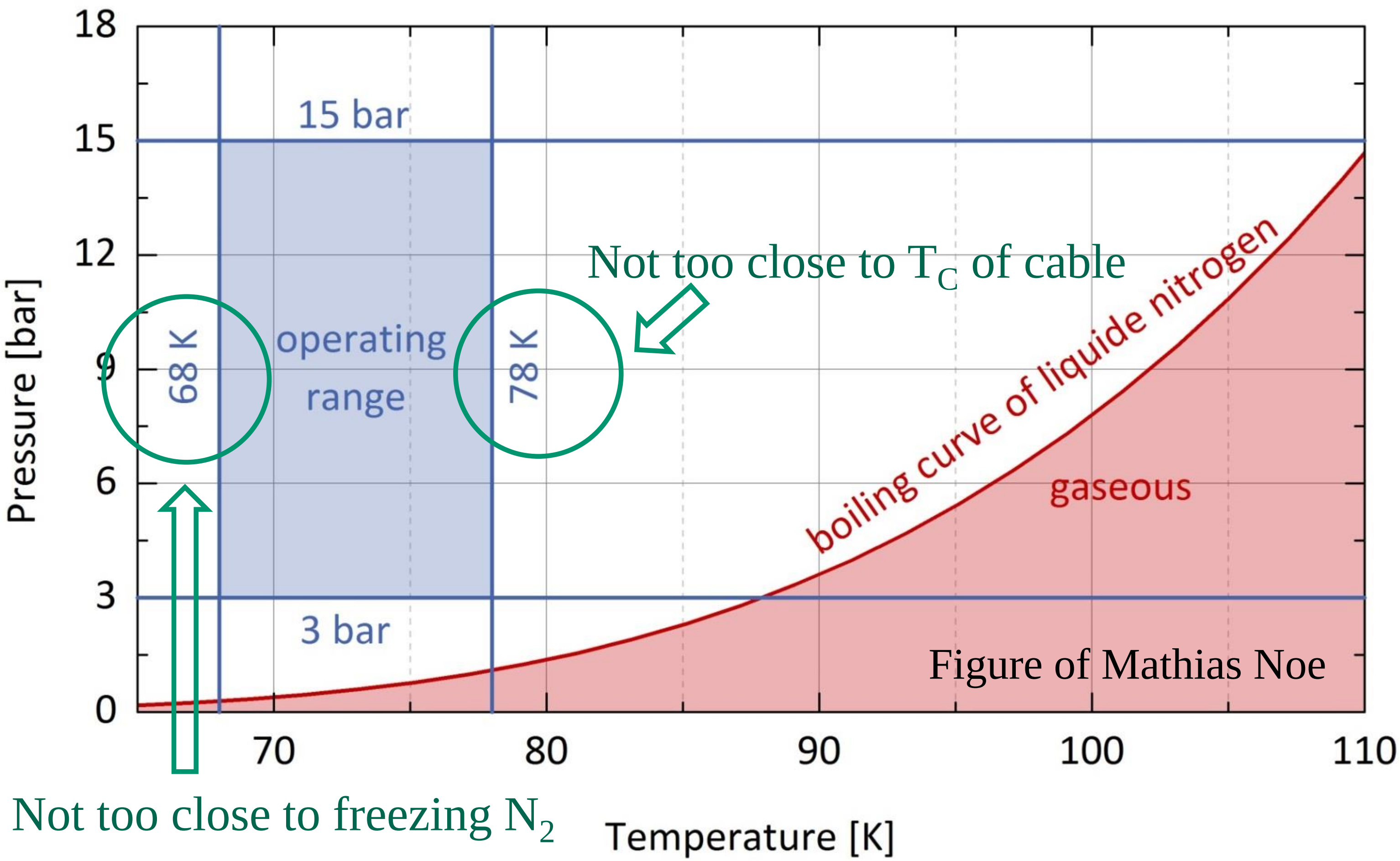
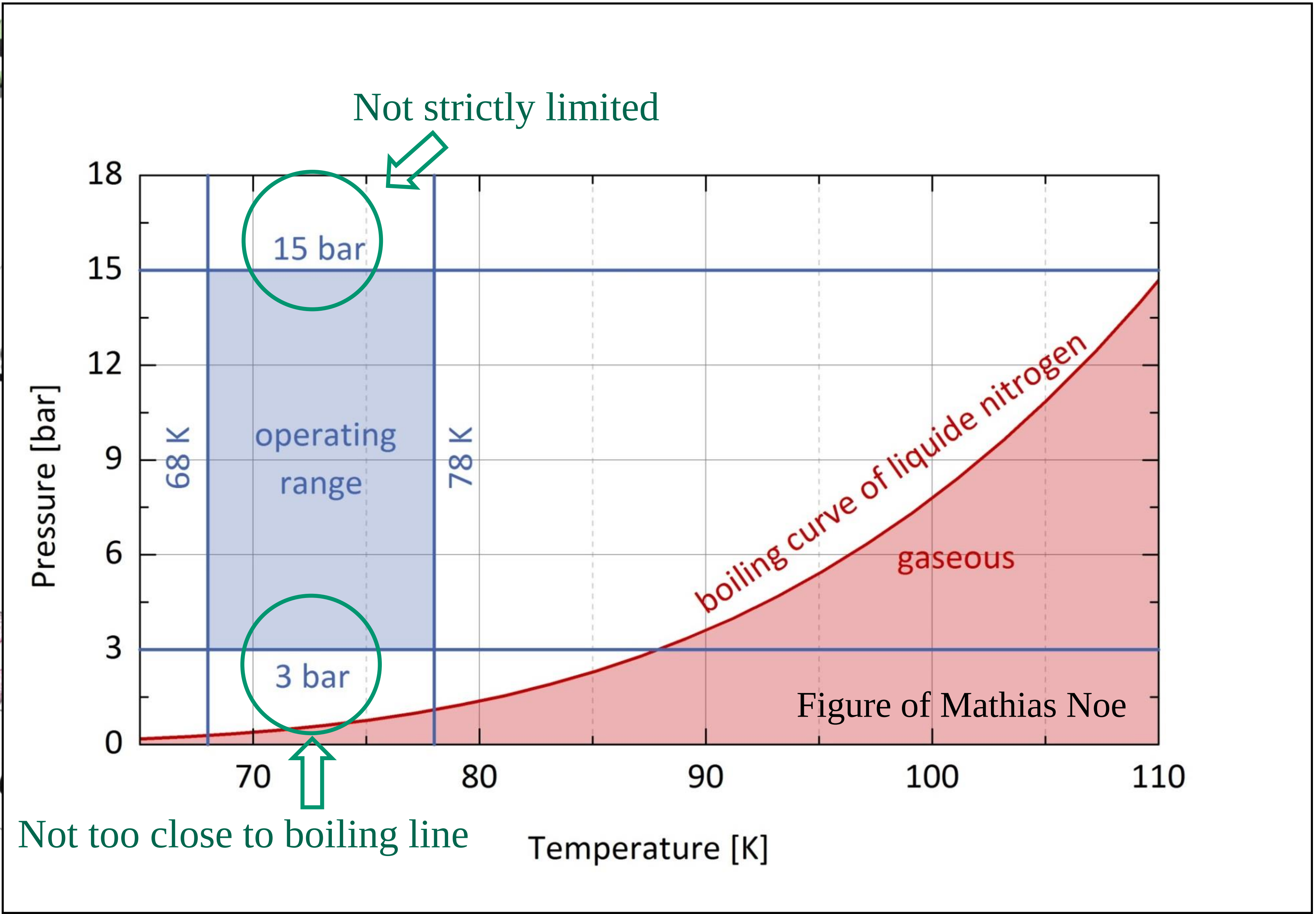
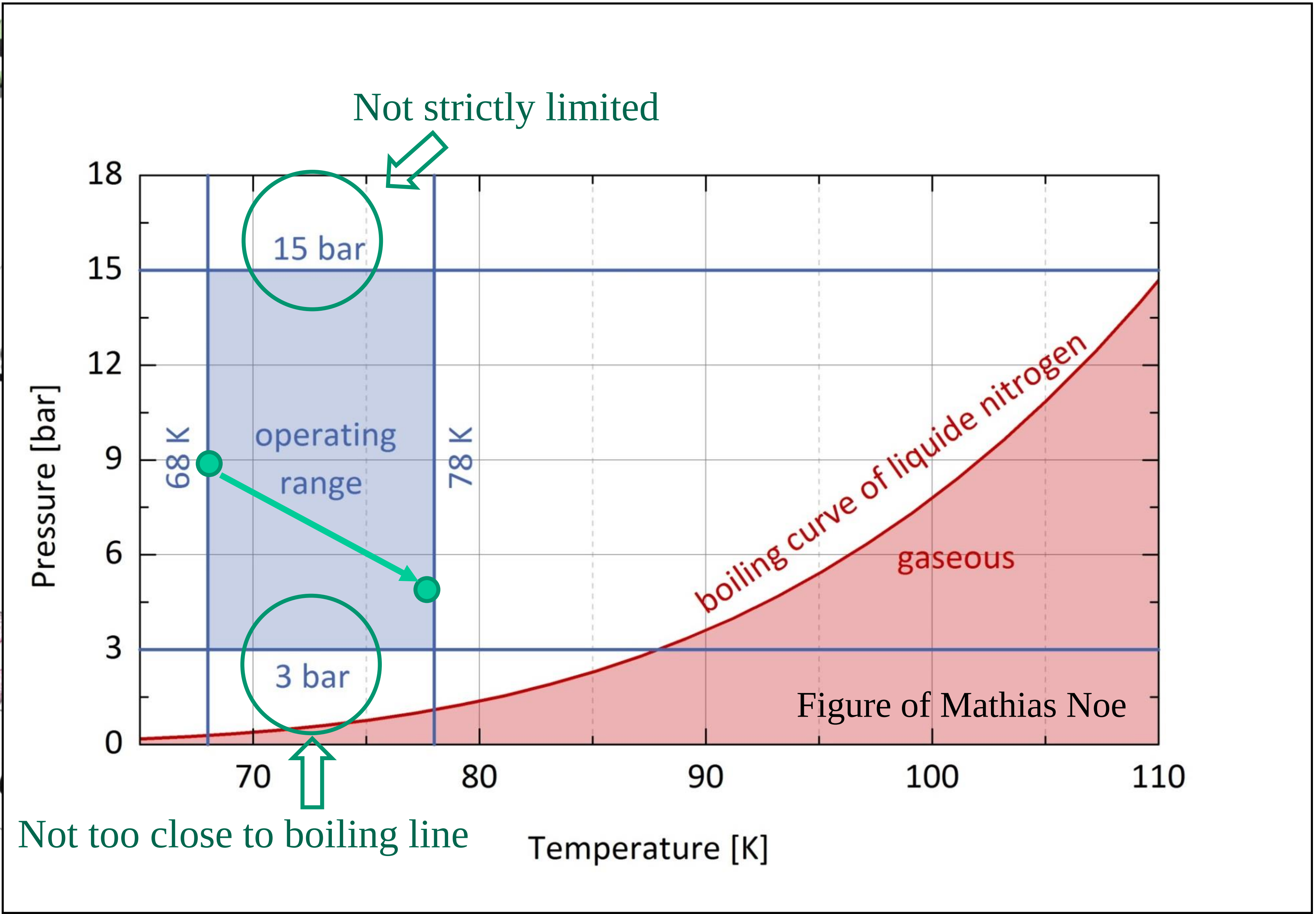


Figure of Mathias Noe

What temperature?



What temperature?

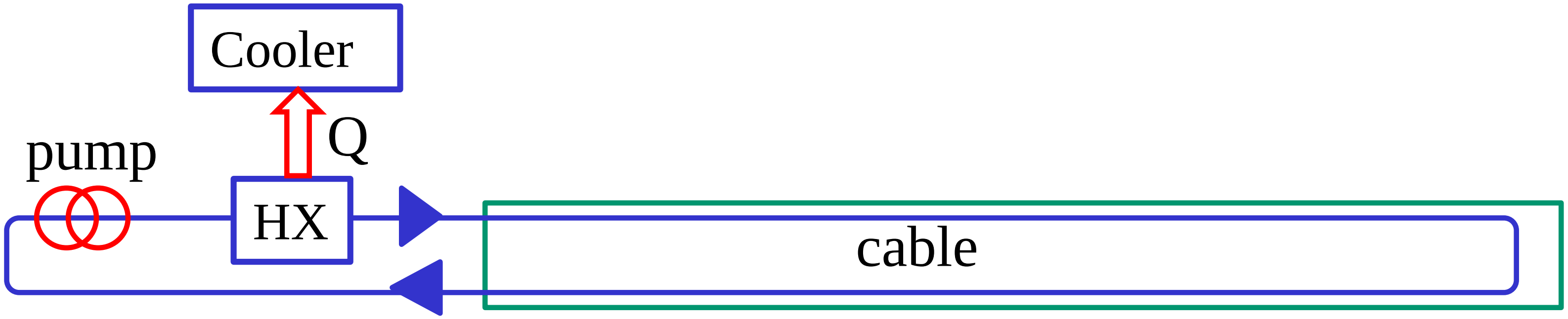


Cooling system

What if cooler fails?

Thermal buffer needed:

- e.g. pumped LN2 tank
- or other TSU (phase change)



Cooling system

LN2 tank

Pro: cheaper (LN2 infrastructure already needed at cable)
Con: LN2 transport needed (ca 1 truck in 2 days)

Mechanical cooler

Pro: No LN2 transport needed
Con: More expensive

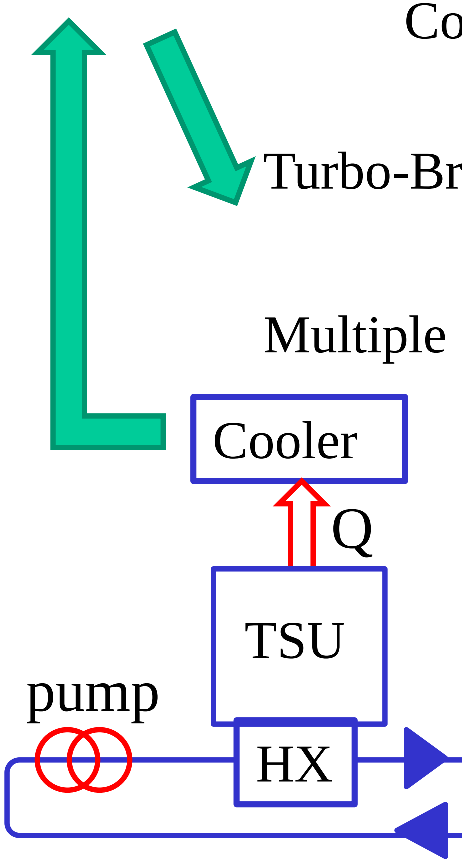
Turbo-Brayton cooler

Pro: less complex: easier operation and installation (compared to Stirlings)
Con: more expensive (?)

Multiple Stirling coolers

Pro: (compared to TB cooler)
- redundancy
- can be used in both ends cooling
- less expensive (?)

Con: more complex

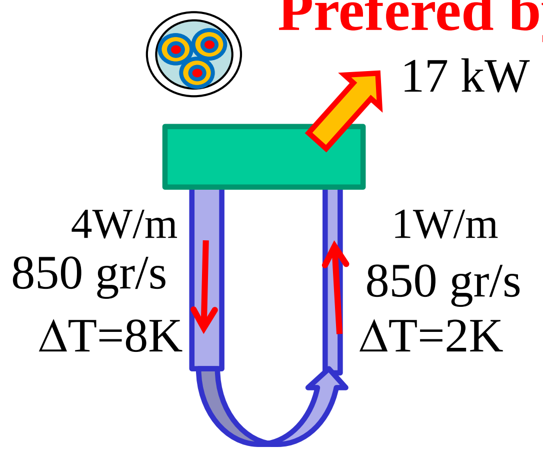


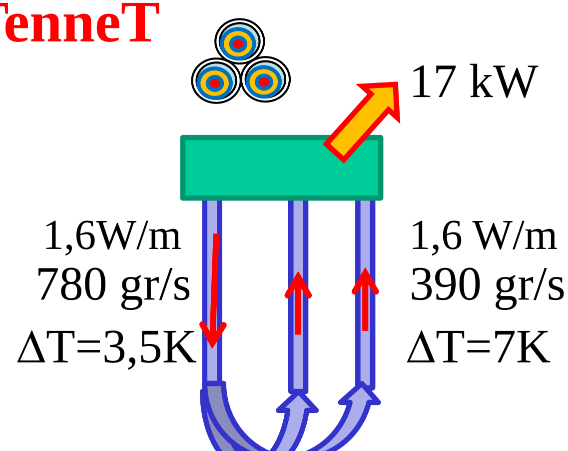
cable

Cable geometries and cooling stations

One-end cooling

Prefered by TenneT





$$\dot{Q} = \dot{m} c_P \Delta T$$

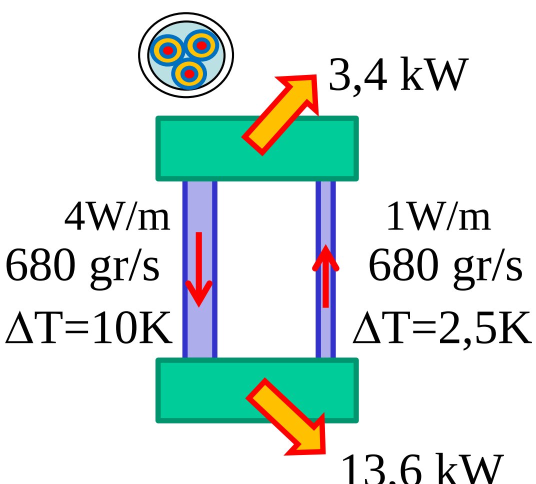
LN2: 800 gr/liter

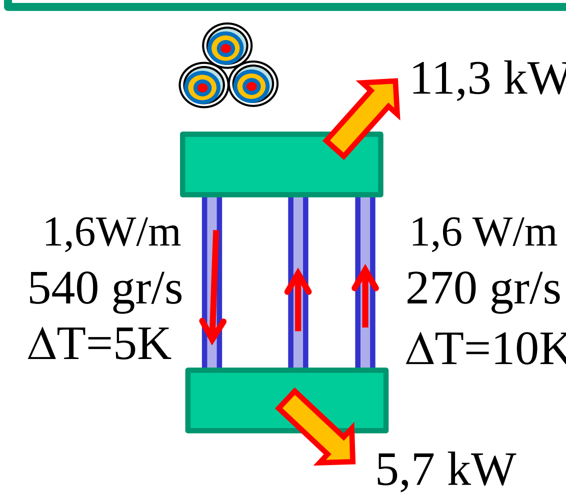
800 gr/s = 1 liter/s

Tapping water:
0,1 – 0,2 liter/sec

Advantage of cooling at both ends in stationary case is lower required flow rates (because of larger ΔT)

Both-ends cooli





However, more complex in installation and operation, higher cost

AND, LN2 only at one end

Cool-down time?

Outage time in case of damage: 2 – 3 weeks (including repair.....)

TenneT specifies cool-down time of 7 days max
(note: pumping will also require about 1 week!)

Limited by installed cooling power (perfect HX)
$C_{cable}(T_{start} - T_{end})/Q_{cool}$ Typically 5 days
Can be shorter by larger Q_{cool} at cool-down

Intrinsic limit by cable thermal time constant RC. Imagine outer (neutral) conductor is extremely rapidly cooled to 70 K. Inner core shows step respons, roughly takes 5RC, typically ½ day:

- Neutral conductor will not like T drop of 200 K at t = 0
- Neutral conductor shrinks by 10 to 20 m

Cool-down time?

Outage time in case of damage: 2 – 3 weeks (including repair.....)

TenneT specifies cool-down time of 7 days max
(note: pumping will also require about 1 week!)

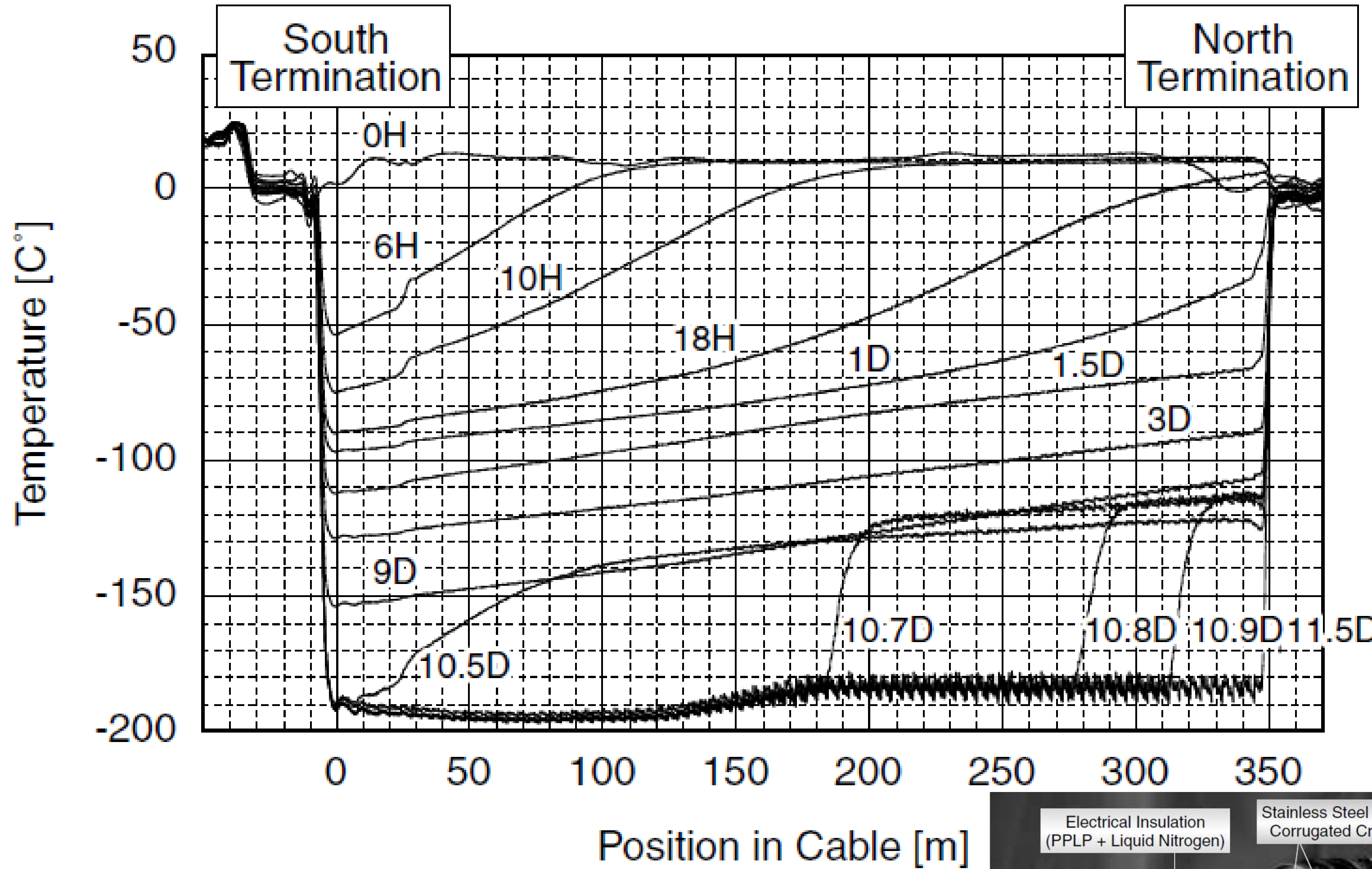
In practice: limited by gas-phase (low density, high pressure drop)
More rapid cool-down: larger diameters,
but then: - more heat load
- more expensive (material and installation)

Allowable cool-down speed is limited by thermal stress effects/damage in cable: What speed is acceptable?

Often used for system cool-down (e.g. CERN): max 1 K/h

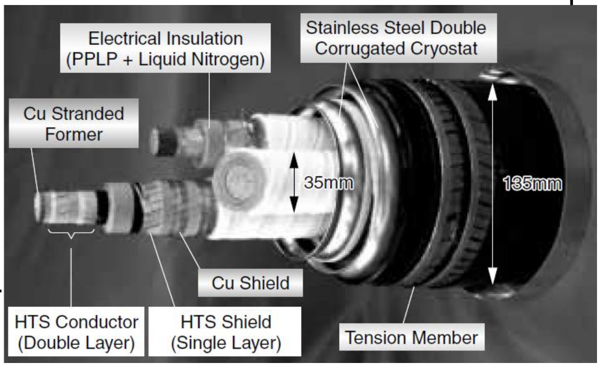
But what about local gradients during cool-down?

Simulation (FEM model) Model applied to Albany Cable cool-down

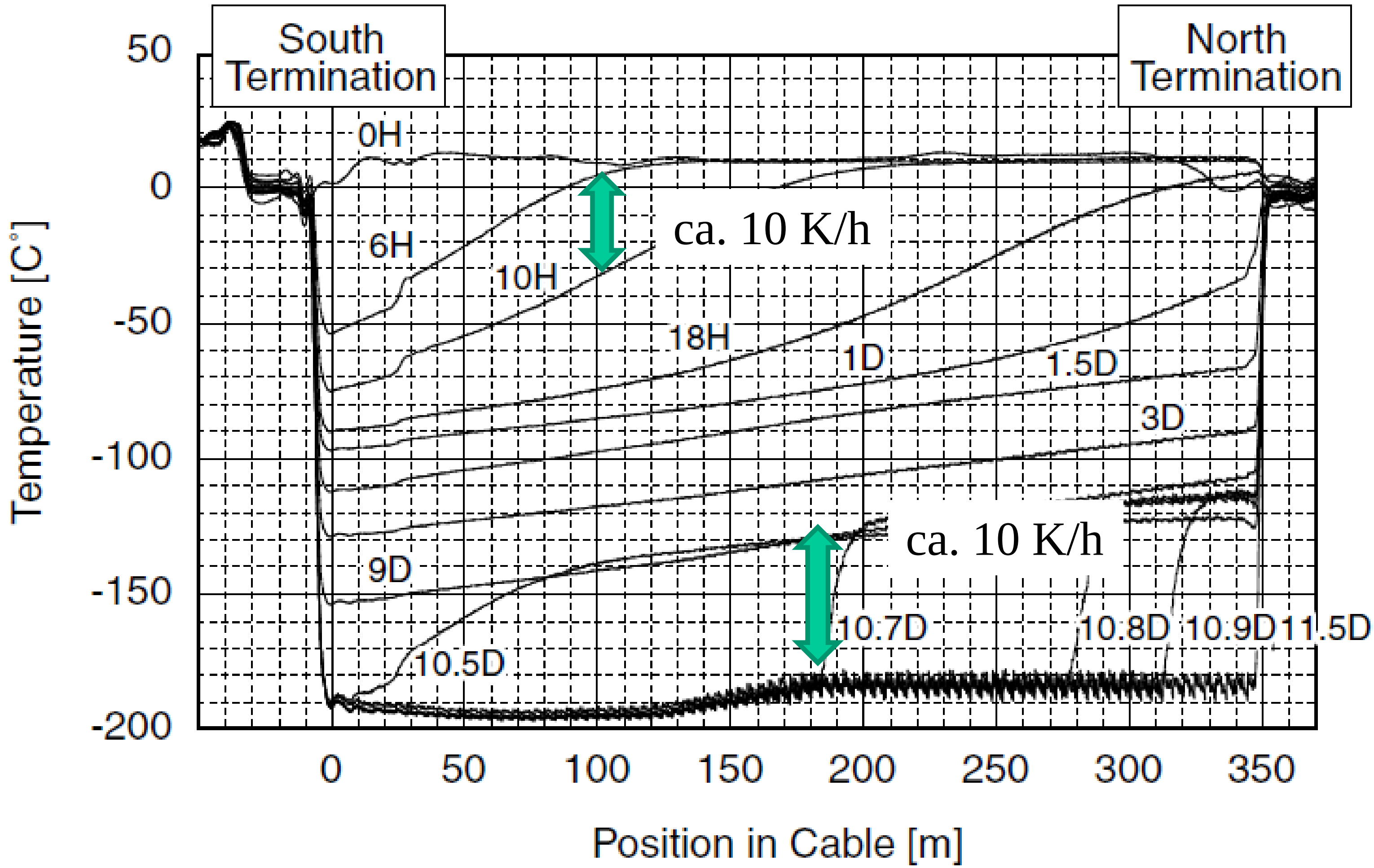


GN2 cooling to -150 ºC takes 9 days
Then LN2 cooling takes 2,5 days

(350 m, 34,5 kV)



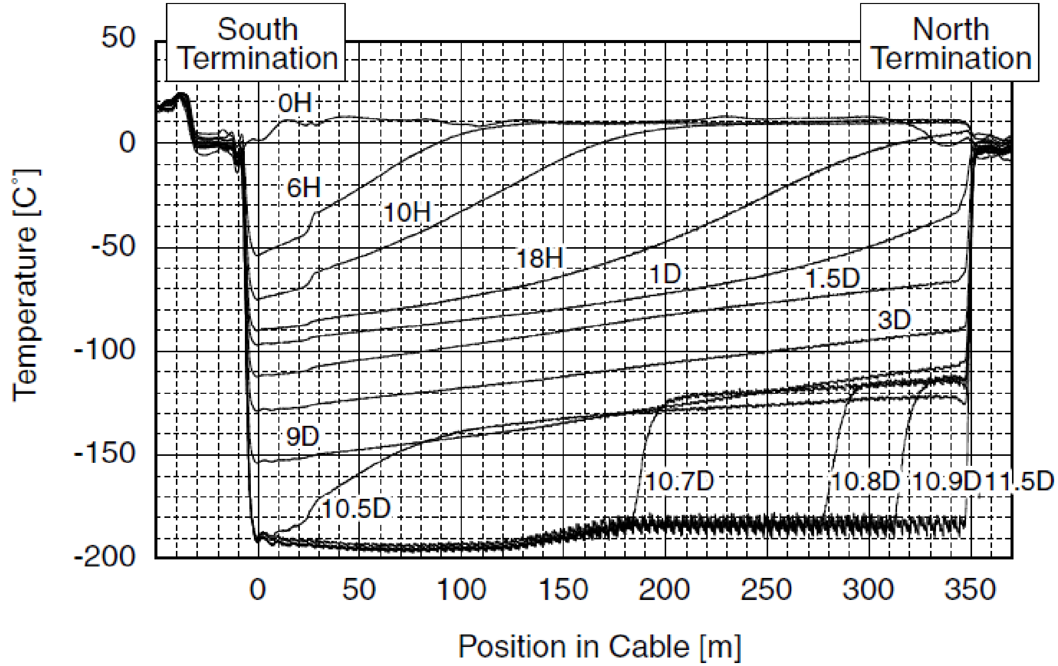
Simulation (FEM model) Model applied to Albany Cable cool-down



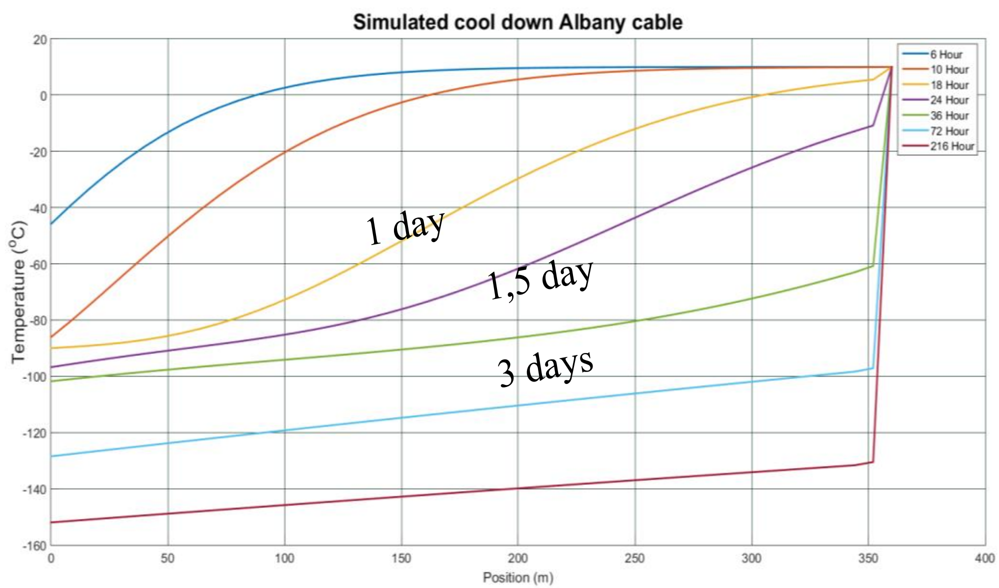
GN2 cooling to -150 ºC takes 9 days
Then LN2 cooling takes 2,5 days

Model for single-phase gas flow
(Gas phase determines cool-down time)

Simulation



Model applied to Albany Cable cool-down



Result of simulation depends on gas inlet conditions (flow rate, temperature)

SupernetNL cable simulation

Part	Radius (mm)
Former	23
Cu + HTS	25
PPLP	40
Cu+ HTS	41
Flow channel	?

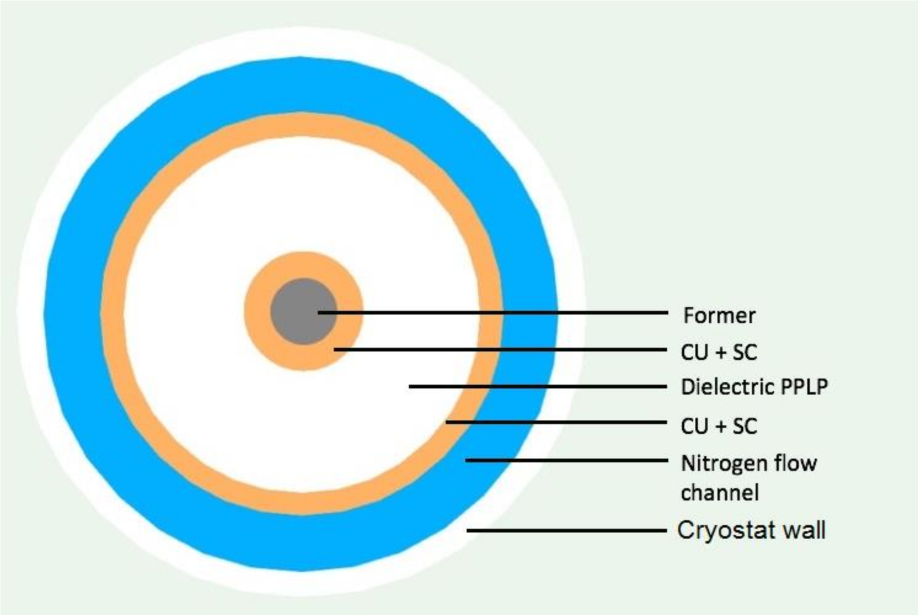
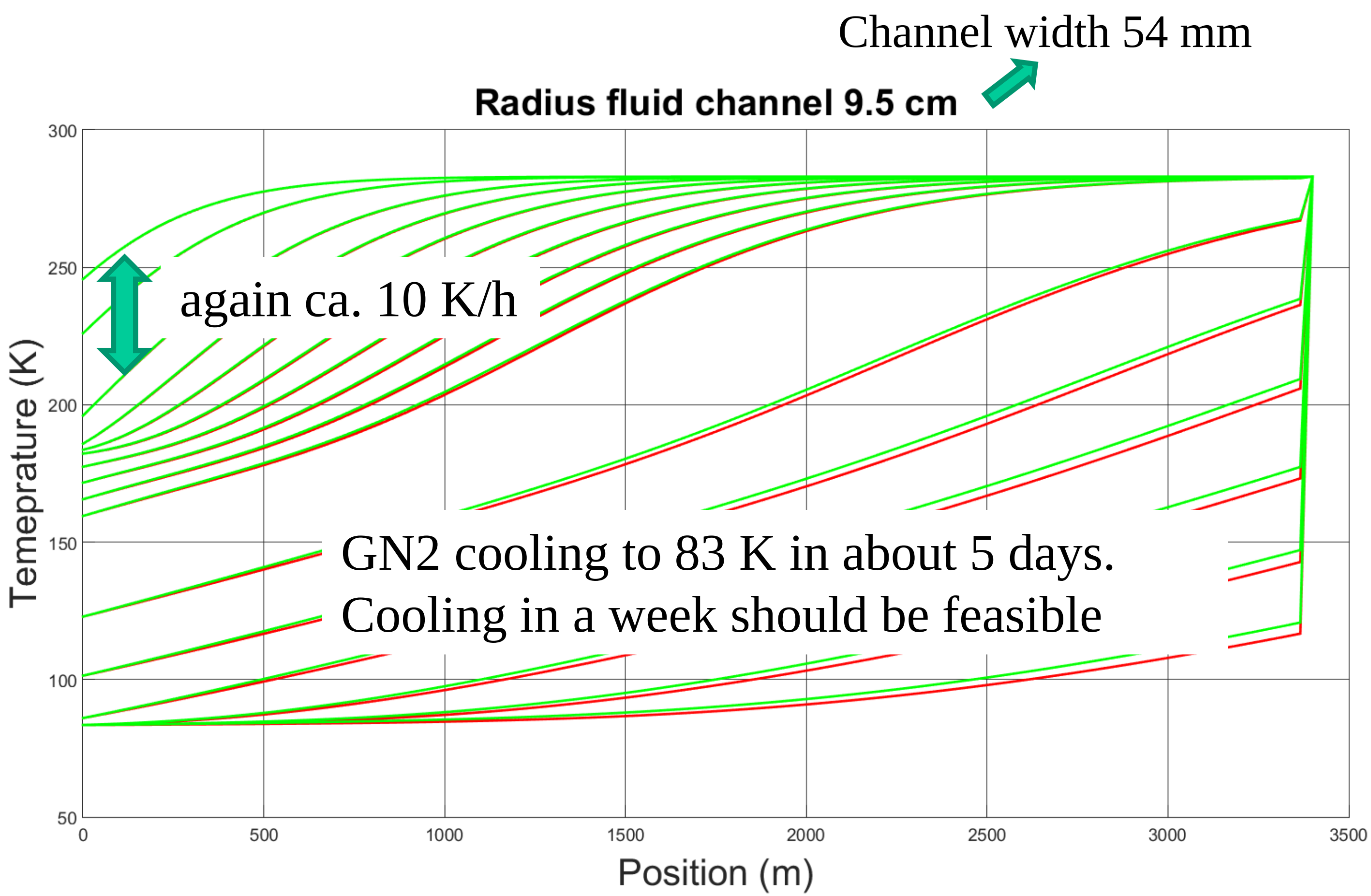


Table 7: properties

property-material	Copper [7]	PPLP	Effective value
c_p	250 J/kgK	750 J/kgK [8]	550 J/kgK
ρ	7896 kg/m^3	1098 kg/m^3 [8]	3817.2 kg/m^3
κ	446.47 W/mK	0.05 W/mK [9]	178.5 W/mK

SupernetNL cable simulation



heat leak 0,8 W/m

heat leak 1,5 W/m

Inlet: 10K/h 283K – 183K
and 3K/h 183K – 83K

ΔP = 1 bar

Flow ca 250 gram/s (4x Albany)

Shrinkage (dynamic)

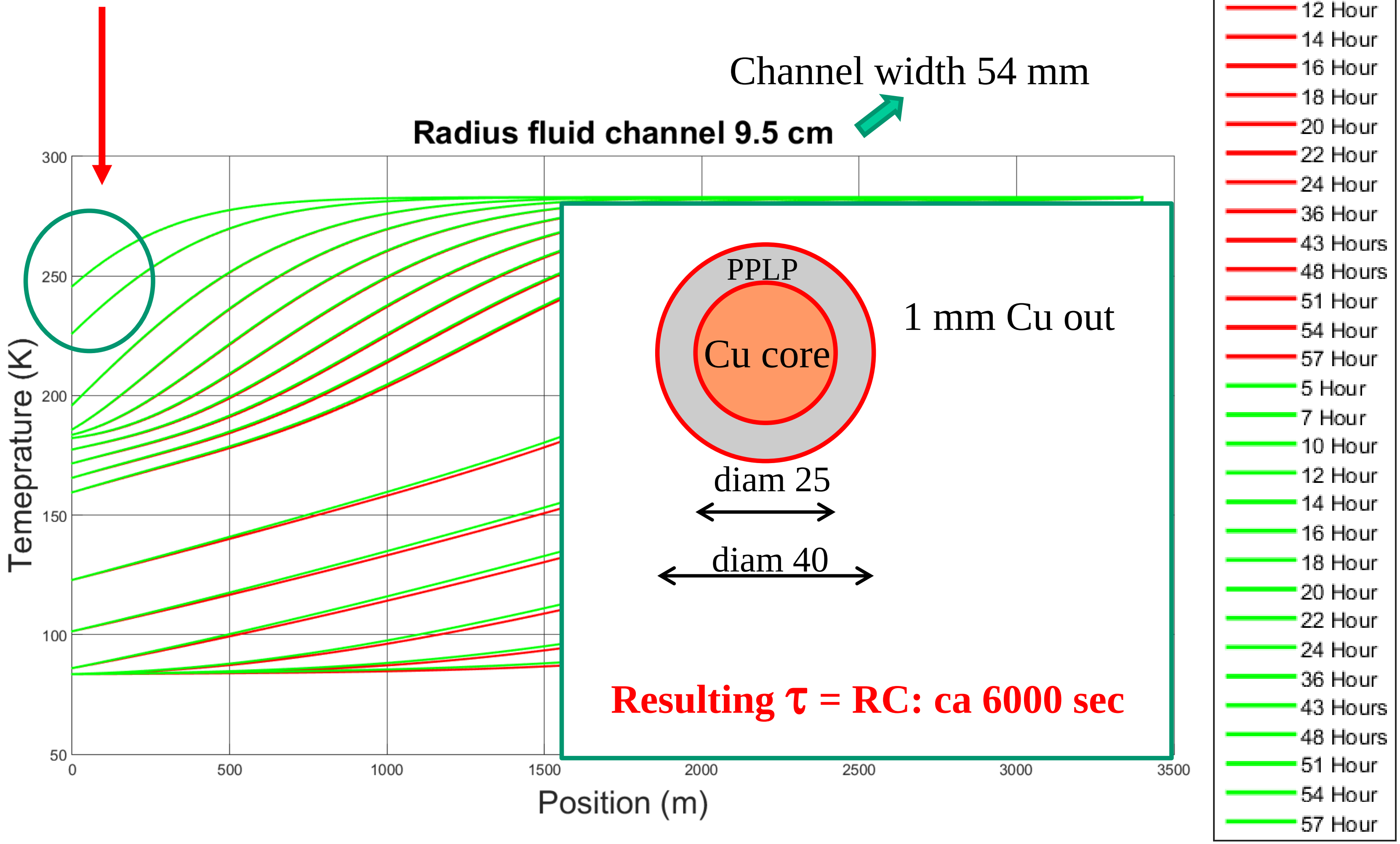
Shrinkage:

- Overall cable: Total cable will shrink 10 – 20 m
  can be dealt with, but "issue" is at bends

- Local: core versus outer (neutral) conductor

Shrinkage (dynamic)

In 6000 sec distance 150 m: ΔT about 20 K: strain 0,03% = 5 cm
Inner core may like to move by 5 cm wrt outer Cu



Status and Planning

- SupernetNL is turnkey project (cable system plus civil works)
- Kick-off October 2015
- Selection phase in May 2107
- 3 parties selected: Nexans, NKT Cables and LS Cable
- Cable and Civil Specifications have been sent out in July
- August: 1st Clarification Meeting
- September: 2nd Clarification Meeting
- Initial offers expected 1st week of October
- Mid October: Clarification Meetings with separate parties
- BAFO (Best And Final Offer) scheduled mid November
- Selection of final candidate and concept
- Decision Go/No Go by Investment Board and Executive Board
- Cable scheduled to be in operation mid 2019

Conclusion

SupernetNL Cable Project:

TenneT contact: Shima Mousavi Gargari:
shima.mousavi.gargari@tennet.eu

- 110 kV AC, 3,4 km
- National consortium
- 3 parties selected (turnkey: cable + civil)
- Final selection end of 2017
- Cable scheduled to operate in 2019

Issues discussed:

- Cooling power estimate 17 kW
- Cooling configurations considered
- Typical T margin 10 K
- FEM model: 1 week cool-down feasible (dominated by gas phase)
- Local cool-down speed typical 10 K/h
- During cool-down core displaces w.r.t. outer conductor several cm