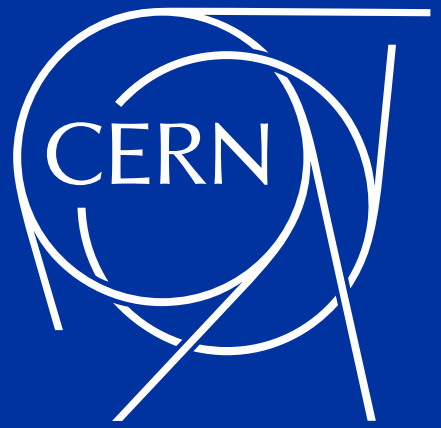


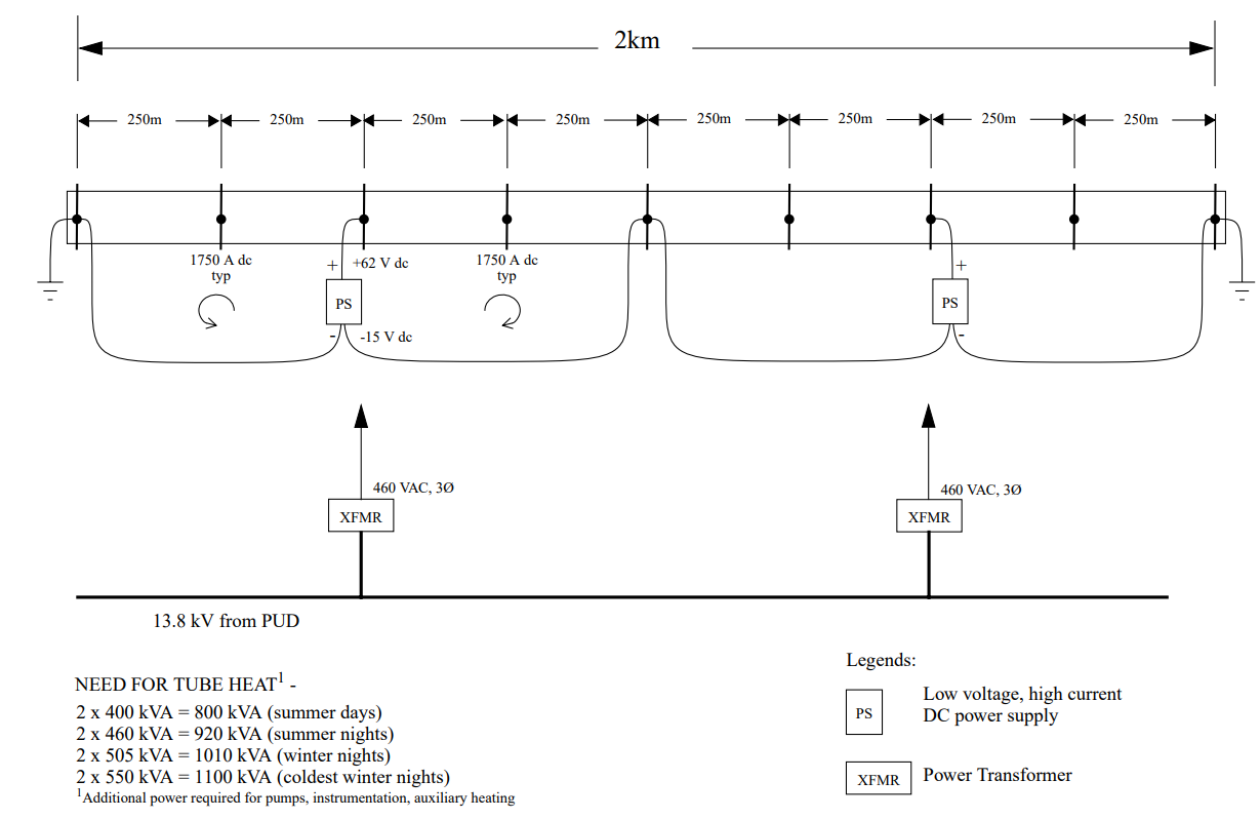
Thermal insulation for GWDs beam pipe vacuum systems

Carlo Scarcia, Karl Owens

BWT3, 2025/10/01

The bakeout of GWD beam pipes

To efficiently bakeout the GWDs beam pipes, we can re-use direct joule effect (beam pipe = conductor).



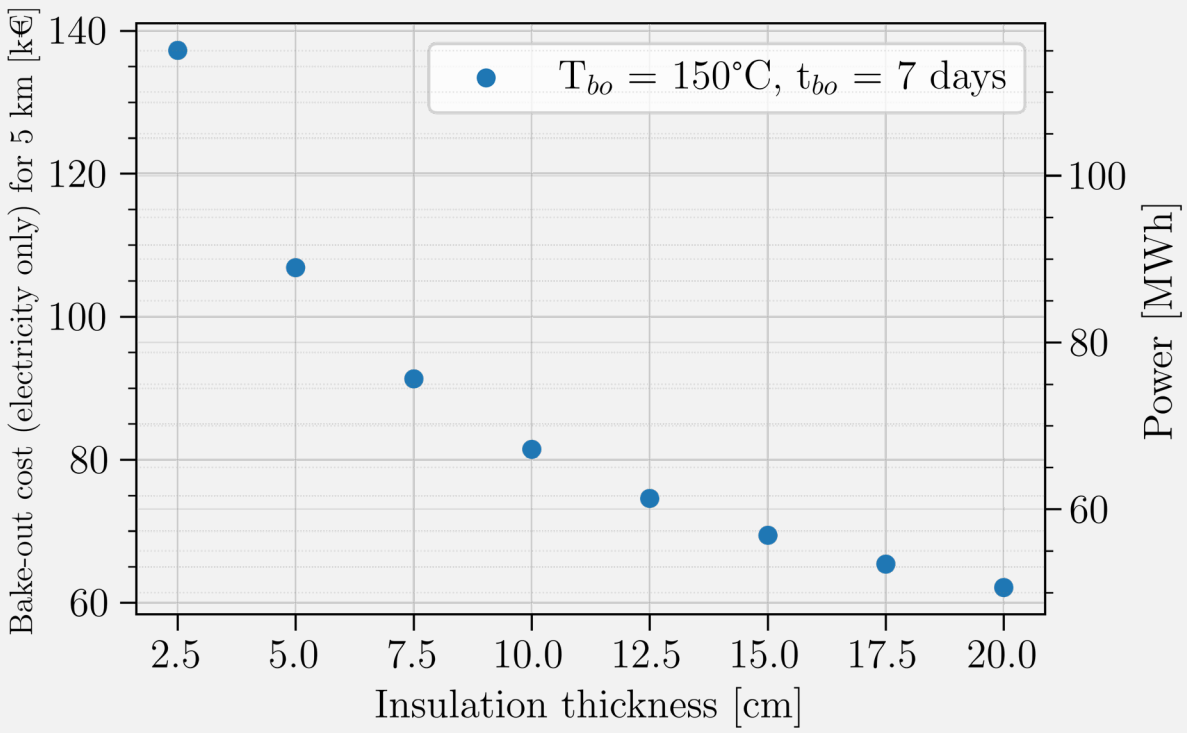
*LIGO bakeout electrical heating power (*LIGO-G970071-00-P)

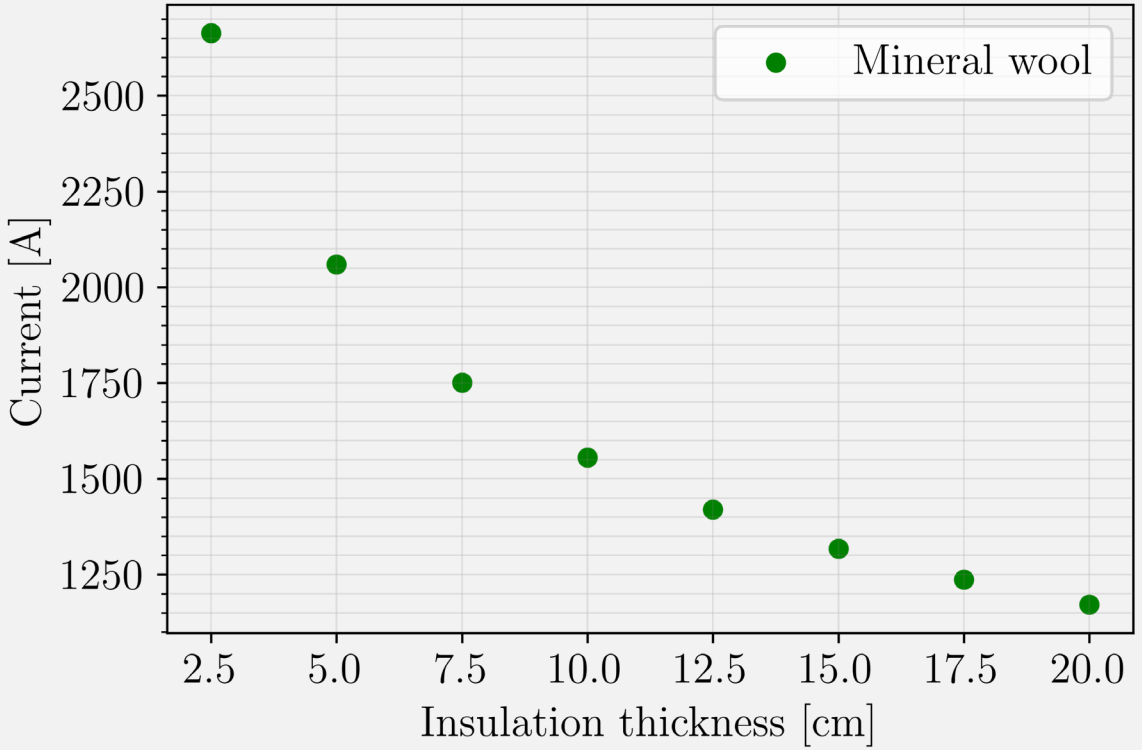
Electrical test of a power supply on an ET corrugated prototype (400 A max)

Why do we need insulation?

Limiting heat losses = limiting needed current = lower costs

The system is foreseen to be baked one, maximum two times over 50 years of operation (150°C max).





$K_{mineral\ wool}$: 3.65E-7 ΔT^2+1.44E-4*ΔT+4.89E-2 W m^{-1} K^{-1}, ΔT: 130°C (150°C-20°C). Convection coefficient (h): 5 W m^{-2} K^{-1} (calm air, no forced ventilation)

The problem of LIGO and VIRGO approach

Insulation: 15 cm mineral wool (double layer of 7.5 cm) **permanently installed.**

For ET

Surface to be covered: ~380.000 m^2 (120 km)
Cost of insulation (mineral wool 10 - 15 cm): ~48 – 60 €/m^2

Total insulation cost [€]: ~ 18 - 23 M €

Other concerns:
Depreciation cost if permanently installed?
Storage?
Sustainability?
Cleanliness and dust generation?
Safety (smoke, fire generation, installation, etc.)?

Images courtesy of M. Zucker and R. Weiss

Some alternative materials to mineral fibers

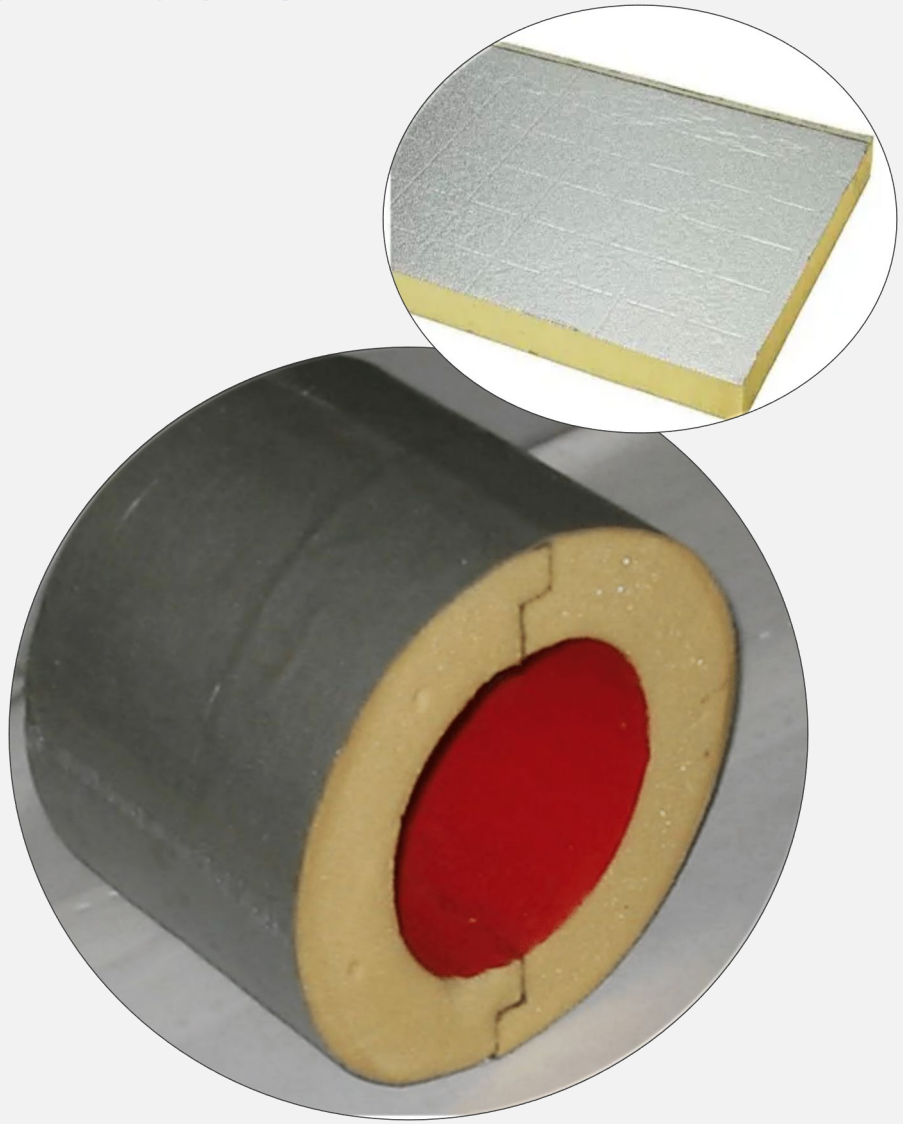
Aerogel

- **Thermal Conductivity (λ) Range: 0.015-0.025 W $m^{-1}K^{-1}$**
- **Pros**
  - **Extremely low thermal conductivity**
  - Thin
  - **Lightweight**
  - Hydrophobic
  - Flexible
- **Cons**
  - **Expensive**
  - **Brittle**
  - **Powdery debris**
  - Irritant and possibility of respiratory problems

Some alternative materials to mineral fibers

Polyurethanic foam

- **Thermal Conductivity (λ) Range: 0.02-0.03 W $m^{-1}K^{-1}$**
- **Pros**
  - **Very low thermal conductivity**
  - **Available in various thicknesses**
  - **Highly durable**
  - **Lightweight**
- **Cons**
  - Sometimes more expensive than fibre-based materials
  - Off-gassing
  - **Lower operating temperature**



Development of a new thermal insulation for ET

No explicit requirement from the project (ET). Project developed by CERN and PIEP (PT)

	Target value	Maximum value
Insulation thickness [cm]	10	
Form	**Reusable shells**	
Maximum operating temperature [°C]	400	300
Thermal conductivity k [W m^{-1} K^{-1}] (at 20°C)	< 0.04	< 0.05
Thermal conductivity k [W m^{-1} K^{-1}] (at 150°C)	< 0.05	< 0.06
Reaction to fire (EN 13501-1)	Euroclass A1	Euroclass A2
Smoke production (EN 13501-1)	S1	S1
Droplets generation (EN 13501-1)	D0	D0
Water vapour resistance factor	<1	Not specified

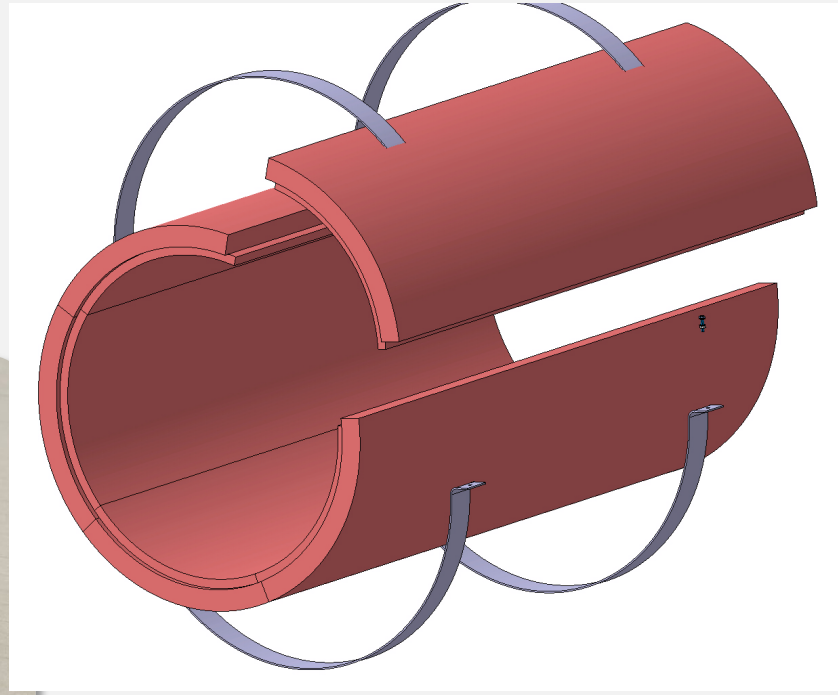
Mechanical properties yet to be determined

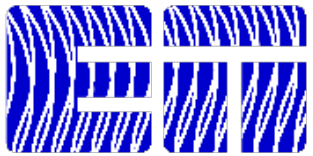
Development of a new thermal insulation for ET

Objective of the project: development of sustainable, cheap and inflamable insulation for Einstein Telescope based on:

- Cork + Bio-phenolyc foam
- Fire retardant modified PIR

The material will be castable and made in shells.
Installation in ET-PS foreseen for Q3 2026





EINSTEIN
TELESCOPE

Degree of flammability	Smoke production	Droplets generation
A1 = non-combustible, No contribution to fire	**S1** = Low emission rate and speed	**D0** = No droplets
A2 = limited combustibility, Very limited contribution to fire	**S2** = Medium emission rate and speed	**D1** = Limited generation of droplets
B = Combustable, Limited contribution to fire	**S3** = High emission rate and speed	**D2** = Not classified
C = Combustable, Minor contribution to fire		
D = Combustable, Medium contribution to fire		
E = Combustable, High contribution to fire		
F = Combustable, Easily flammable		

Source: KNAUF insulation