# CABLEGNOSIS project: ageing studies on insulation materials and superconducting wires for cable applications

**T. Spina**[1], R. Tebano[1], C.E. Bruzek[1], L. Soldati[1], A. Barutti[1], G. Gamper[1], U. Melaccio[1], P. Corsaro[1], G. Bino[1], M. Abdolahi[2], M. Yazdani-Asrami[2], W. Song[2], S. Hole[3]

*[1]ASG Superconductors S.P.A., Genoa, Italy; [2]University of Glasgow, UK; [3]ESPCI, Paris, France*

**– Abstract –**

Power cables are expected to be operational in grids at least for 40 years. To ensure lifetime and to prove their reliability, standardized type and PQ tests are carried out, e.g., withstand voltage testing. Usually, polymeric materials (typically polyethylene) are used as dielectric materials. Standard testing procedures integrate extrapolations using the analytical ageing laws mostly related to thermal and voltage ageing to investigate their impact on lifetime of the cable insulation. Superconducting cables are effectively cooled and maintained at a cryogenic temperature, commonly below 77 K. In such conditions, one can expect different ageing mechanisms to be dominant rather than thermal ageing, and consequently ageing laws might be different that will impact standard type tests.

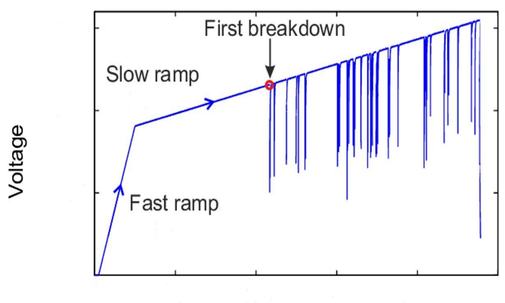
To perceive the ageing law and guide the future process of manufacturing and designing techniques for prognostic health management of superconducting cables as well as to predict when maintenance might be needed, ASG superconductors, University of Glasgow (UofG) and ESPCI (École supérieure de physique et de chimie industrielles de la ville de Paris) are involved in work packages related to the ageing mechanisms affecting both insulation materials and superconducting wires within the framework of CABLEGNOSIS project [1].

This article presents insights on the ageing mechanisms at cryogenic temperature, an innovative prediction methodology based on artificial intelligence and strategies to accelerate the ageing and to acquire accurate data, the best measurements techniques will be discussed.

## The need of ageing laws

The development of ageing laws for cable applications is essential to ensure long-term reliability and safety, particularly in high-stress environments such as power and railways grids and industrial plants.

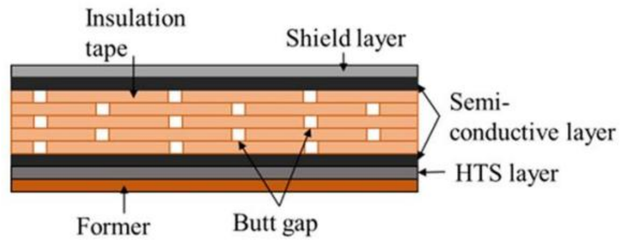
Resistive cables undergo degradation due to thermal, mechanical, chemical and electrical, and well-established ageing laws help to predict their lifespan and guide maintenance strategies. Extending these principles to superconducting cables requires adapting models to account for unique factors as low-temperature material behavior and electric and mechanical stresses. The Cigré technical brochure [2], collects recommendations for testing dc extruded cable systems for power transmission at a rated voltage up to 800 KV but with poor information on ageing laws for resistive cables. No information on cryogenic insulation and testing are available. Even if some data on electrical insulation systems at cryogenic temperatures could be found in [3] it is mandatory to provide a valuable extension. This is the subject of the present work.




Experimental data will be used to fit the relation:

$$\int_0^{t_{BD}} V^n \cdot t \, dt = const$$

where:
V=Voltage; t=time; $t_{BD}$=Breakdown time;
n=life constant related to the ageing




The structure of insulation is complex [4]. It is a composite and consequently heterogeneous. The tapes constitute the structure, but several different gaps are filled or impregnated with coolant. In such architecture, some local electric field enhancements (tape edges) could be found that would change locally the breakdown voltage values and consequently affecting the s.c. cable lifetime.

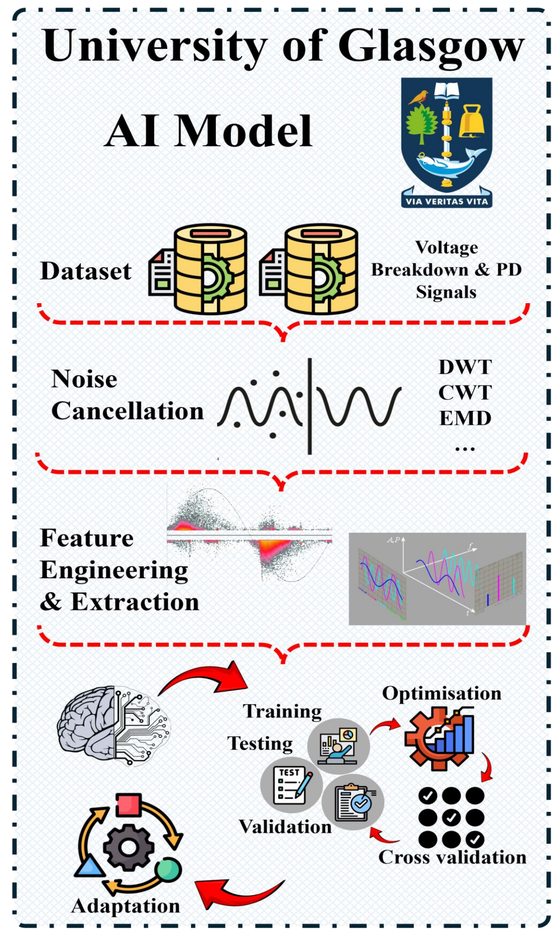
## Artificial Intelligence (AI) degradation models

Given the lack of data on SC cable ageing, the framework's predictive accuracy relies on generating a large experimental dataset out of accelerated ageing tests (drift current, low frequency impedance and PD signal during voltage ramp up to breakdown), since AI-driven models require large amounts of data to capture the underlying characteristics of cryogenic degradation.

A pre-processing methodology can be applied, using techniques like data processing, analytics techniques (e.g., wavelet transform), and filtering experimental noise, followed by feature extraction through statistical analysis or the generation of Phase-Resolved Partial Discharge patterns, for achieving accurate predictions.

Ageing and degradation of SC cables can be investigated and analyzed using classification and regression tasks of AI models (tree, boosting, and neural network-based models).

The CABLEGNOSIS project is developing an AI-driven prognostic framework for SC cable ageing, characterized by the challenges of cryogenic operation and material degradation (impact of using $MgB_2$ wires in hydrogen). The framework provides capabilities for generalization, extrapolation, non-linear modelling, and accurate prediction under complex multi-stress conditions.



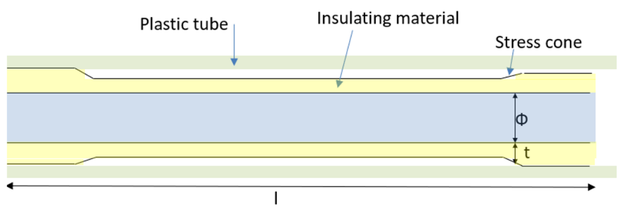

## Experimental set-up for electrical ageing of insulated materials

### "Dummy" Sample

In SCARLET project [5], instantaneous VB and PD tests in different media ($LH_2$ , $LN_2$ and GHe) are carried out. In CABLEGNOSIS we extend the study by estimate the lifetime of cables reducing the voltage ramp until the final breakdown.

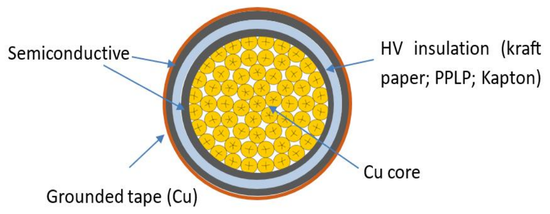
Different insulated materials will be tested and «dummy» samples, i.e. w/o s.c. wires, are chosen. The final goal is to compare the effects on the chemical nature of the insulated materials selected: paper, PPLP, and polymers.

**Axial view**




| SYMBOL | MEANING | VALUE |
|---|---|---|
| Φ | diameter | 18mm |
| t | Tape thickness | 50 to 160 um |
| l | length | 2 to 20 m |
| # | N° of tapes | 4 |
| g | Gap distance | 4mm and overlapped |

**Front view**




*Chemical ageing tests in $H_2$ on s.c. wires ($MgB_2$ and HTS) will be carried out in ASG and will be the subject of another communication.*

### Experimental conditions

| PARAMETER | VALUES | COMMENTS |
|---|---|---|
| Test duration | 1week per sample | Compatible with project time (50 samples) |
| Materials | Kapton; PPLP; Kraft Paper | Selected based on dielectric behavior and cost |
| Temperature | 20K; 77K | |
| Coolant media | GHe; $LN_2$ | To mimic $LH_2$ behavior |
| Pressure | 1.5 bar ($LN_2$) 10bar (GHe) | GHe needs high pressure to get HV performances while $LN_2$ can work at atmospheric pressure |
| Voltage | 70kV; 150kV | |

### Test bed

ASG superconductors provides two large cryostats (~2m height for $LN_2$ and 20m long flexible cryostat for GHe).

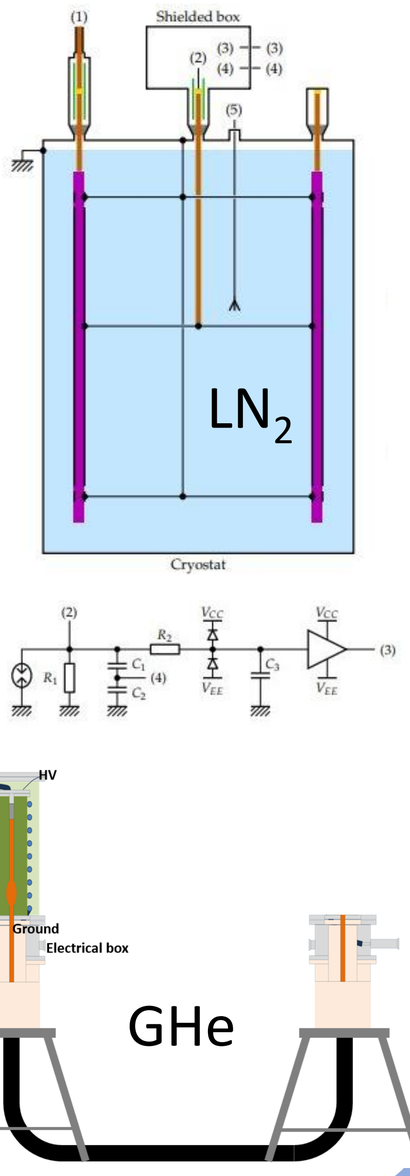
ESPCI provides instrumentation, electronics, acquisition and data logging

32 tested samples are enclosed in $LN_2$ cryostat to simplify cooling. The inner conductor of each sample is connected to a high voltage cable that gets out of the cryostat. These cables are arranged in such a way that one (1) is connected to a high voltage supply and the others are grounded. All outer electrodes are guarded and connected (2) together to only one measurement electronic.

The electronics is protected from breakdowns, allows drift current and partial discharge to be measured respectively at (3) and (4). The power supply is used to apply the high voltage, to detect breakdown and to initiate impedance characterization.

In GHe, only one sample is tested at a time due to the require high pressure and to the capability of cryo-cooler. However, the same instrumentation will be used for detection and logging.

After installation in ASG, measurements will be carried out by remote connection and by in-person meetings. Therefore, all data will be rapidly available to the consortium and measurement protocol could be adjusted at will.




## Conclusion and next steps

The CABLEGNOSIS project is an innovative initiative aimed at developing advanced cable technologies to support the EU's clean energy transition goals for 2050. Key objectives include: development of advanced technologies; superconducting cables; AI based models. CABLEGNOSIS will validate its technologies across five European countries: Italy, the UK, Greece, Hungary, and Cyprus. The project will also conduct feasibility analyses for using superconducting cables in submarine connections and offshore wind parks in the Netherlands and Germany. ASG superconductors, ESPCI (Paris) and University of Glasgow are mainly involved in performing ageing tests on different cryogenic insulating envelopments and superconducting wires and tapes. Commissioning of equipment will be pursued by the end of the year (2025), experimental tests and AI modelling will be carried out during the second quarter of 2026. CABLEGNOSIS project will end in 2027.

## Acknowledgment

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[1] CABLEGNOSIS European Project https://cablegnosis.eu/
[2] Cigré working group B1.62 convened by F. Bononi, "Recommendations for testing DC extruded cable systems for power transmission at a rated voltage up to and including 800 kV", Cigré Technical Brochure 852, 2021
[3] Cigré working group D1.64 convened by N. Hayakawa, "Electrical insulation systems at cryogenic temperatures", Cigré Technical Brochure 846, 2021
[4] P. Cheetham, W. J. Kim, C. H. Kim, L. Graber, H. Rodrigo, S. Pamidi, "Enhancement of Dielectric Strength of Cryogenic Gaseous Helium by Addition of Small Mol% Hydrogen", IEEE Trans. Appied Supercond, vol. 27, no. 4, 2017
[5] SCARLET European Project https://scarlet-project.eu/project/