Allegato A : Brief description of the training project

- **Title of the Training Project:**
  Study of the effects induced by radiation with high energy particles on ferrous-based superconducting materials for magnetic confinement fusion applications
- **Description of the scientific and educational objective:** *(min 1.000 caratteri - MAX 5.000 caratteri)*

Scientific objective:

Project description:
The scientific activity for the proposed thesis is framed within a broader activity that ENI has started a few years ago in collaboration with various CNR institutes and universities that have magnetic confinement fusion as their theme. An enabling technology that allows a leap forward with applications that go to the heart of the guidelines proposed by the NGE program, which is addressing PNRR. One of the purposes of the agreement in place is to increase skills in the area.
Specifically, the project envisages the development of superconducting materials at a high critical temperature suitable for making magnets for fusion reactors.
There are several experimental reactors that explore the possibility of developing magnetic confinement fusion technology at an industrial level. One of these involves the magnetic configuration known as 'Tokamak', where the materials that make up the coils of the magnets are subjected to strong radiation during the melting process. The ferrous-based superconductors have been shown to be particularly suitable for their resistance to expected radiation damage.

Classification:
Ferrous-based superconductors (IBSC) are semimetallic materials with transition temperatures to the superconducting state up to 55K, which combine at a sufficiently high critical temperature (Tc) the possibility of working at high currents (high JC), allowing to obtain intense fields magnetic. These materials also show a fair isotropy at high temperatures and resistance to radiation damage. Among the materials of this family, Fe (Se, Te) has some advantages since it does not containing arsenic, having a simple structure and a fair Tc compared to the materials of the same family. The attention of the doctoral project is therefore focused on these materials.

Objective:
The main objective of the research project is the study of thin IBSC films grown on different substrates and the effects of irradiation at cryogenic temperatures on such films.
It has been seen that, under some conditions, irradiation leads to an improvement of the material in terms of critical current JC, this is because defects are created that can block the flow lines, with the creation of pinning centers that raise the critical current JC of the material. The study of such defects also on an atomic scale is important if the characteristics of the film are correlated with its superconducting properties.
The PhD activity involves the chemical-structural characterization of these films, using techniques related to transmission electron microscopy (TEM), electron spectroscopy techniques (EELS and XPS) and Raman microscopy.

Training objective:

During the PhD period the candidate will acquire skills on:

1) questions inherent to the topic of the scholarship
2) sample thinning techniques for TEM measurements (mechanical thinning and fabrication of lamellae using focused ion beam (FIB)).
3) TEM analysis and use of related techniques (electron diffraction, imaging techniques, CBED, EFTEM)
4) c-corrected STEM analysis (mass contrast imaging, EELS and EDX spectroscopy)
5) XPS electron spectroscopy and Raman microscopy
6) Use of programs and tools for data processing and analysis

Furthermore, we will acquire knowledge on thin film deposition techniques, transport measurements at cryogenic temperatures and magneto-optical measurements.

- **Company Supervisor:** _____Antonio Trotta_____

Methods of carrying out training and research activities:

Training activity:
• Participation in lectures / seminars provided during the PhD training course in Physics at the University of Messina
• Participation in training courses / seminars / schools on topics included in the National Strategy of Intelligent Specialization (SNSI) 2014 - 2020.
• Participation in training courses aimed at encouraging innovation and exchange between the world of research and the world of production.

Research activities:
The research activity will focus on the theme of the development of superconducting materials suitable for the production of energy from nuclear fusion with magnetic confinement, consistent with the themes envisaged by the PNRR. It will be carried out in collaboration with the Institute for Microelectronics and Microsystems of the CNR (Catania) for morphological-structural diagnostics using TEM microscopy. The part of the activity foreseen in the company, lasting six months, at the company Eni S.p.A, will concern the preparation and treatment of materials by irradiation.

Eni S.p.A. will host the PhD student beneficiary of the scholarship financed on the resources of the Ministerial Decree 352/2022 for n. 6 months (min 6 max 18) during the PhD program.

Period abroad for no. 6 months (min 6 max 18) at one of the following institutions:

Ernst-Ruska-Center, Forschungszentrum Jülich GmbH (Germany)
Central Facility for Electron Microscopy, RWTH Aachen University (Germany)
Max-Planck-Institut für Eisenforschung GmbH, Düsseldorf (Germany)

❖ **Effects and expected results with particular emphasis on promoting economic development and the production system::**

The proposed doctoral activity contributes to the development of superconducting materials and superconductivity, developed for devices useful in the fields of energy, research and health, is an enabling technology that allows a leap forward with applications that go to the heart of the lines guidance proposed by the NGE program, which is addressing the PNRR. With reference to the "Make it Green" line, one can think of superconducting grids with almost zero emissions for the distribution and storage of energy, or even superconducting motors for sustainable mobility. Diagnostic machines such as MRI or gantry for hadrontherapy based on superconductors follow the "Make it Health" line. Finally, the proposed scholarship is a good opportunity to encourage young researchers to study science and technology, which open the doors to the green jobs of the future, consistent with the "Make it Strong" line.
Superconducting materials have great potential to bring radical changes to electrical power and high field magnet technology, enabling high efficiency electrical power generation, high capacity lossless electrical power transmission, light weight of small electrical equipment, high-speed magnetic levitation transport, generation of ultra-powerful magnetic fields for high-resolution MRI systems, NMR systems, SMES systems, future advanced high-energy particle accelerators, and not least nuclear fusion reactors technology to which large companies such as ENI S.p.A. they begin to show interest.
The expected results of the PhD program are in compliance with the objectives set by the PNRR and in line with the European Green Deal, providing for the achievement of specific qualitative and quantitative targets, identified in the research project proposed for the scholarship. In addition, the doctoral program provides for a series of connections between the research and innovation areas of PNR 2021-27, of the SNSI and with the thematic objectives (OT) established by the European Green Deal, including:

OT1. Making the EU climate goals for 2030 and 2050 more ambitious;
OT2. Ensure the supply of clean, economical and safe energy;
OT3. Mobilizing industry for a clean and circular economy.