Politecnico di Torino

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PHYSICS

MUR DM 117/ENI - Prototypal design of fusion nuclear reactors: critical aspects for radiation damage

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Context of the research activity	The key enabling technology for the development of compact fusion reactor is that of High-Temperature Superconducting (HTS) tapes, which are capable of generating the necessary high magnetic fields. However, they will be exposed to a high flux of high-energy neutrons and secondary particles, making it urgent to understand fully the physics of the radiation damage process and all the effects of the radiation environment on HTS performance. Progetto finanziato nell'ambito del PNRR – DM 117/2023 - CUP E14D23001960004

	The goal of this project is to deepen the understanding of neutron radiation effects on high temperature superconducting (HTS) tapes in compact fusion reactors. In particular, a fundamental step for modeling the radiation damage in HTS materials is the knowledge of the radiation environment the HTS will experience in the locations of the magnets. The radiation environment will be estimated using Monte Carlo simulations on a full 3D model of the whole fusion reactor design, the required precision is achievable in reasonable times by employing parallelization schemes on high performance computers with the code PHITS. The high computational power is needed also to analyze systematically how variations of the reactor design affect the neutron spectrum, flux and fluence at the magnet position. This neutron spectrum in fact determines the structural damage that will be created in the target material, that can be described starting from the spectra of primary knock-on atoms (PKAs) resulting from the neutron spectrum itself. Starting from this expected radiation environment the candidate will develop accelerated schemes based on Machine Learning algorithms for the quick estimation of some key parameters for the radiation environment and structural damage directly from the design of the reactor, without need of lengthy calculations. In

Objectives	this context, the proposed thesis activity can be articulated in three steps, dealing with: Monte Carlo (MC) simulations to obtain the neutron spectrum, PKA spectrum calculations, ML algorithm development and training. In detail: Step 1: Performing MC simulations to carry out a sensitivity analysis of the neutron spectrum on the magnets of a compact fusion reactor for reasonable variations of the reactor design. In particular, the candidate will start from a full 3D CAD design of an ARC-class reactor, to minimize the uncertainty on the neutron data at the magnet position while individuating fast simulation schemes that would allow a broad investigation of modifications to the reactor design. To achieve this target, a bottom-up approach will be used, by comparing complex simulations with simpler and faster ones that still capture all the relevant information. The output of this step will be a broad dataset of neutron spectra corresponding to different reactor designs. Step 2: Starting from the output of step 1, the PKA spectrum in the HTS is computed for each reactor design, considering all the nuclear reaction channels. This kind of output is instrumental for the investigation of the structural damage in the material through Molecular Dynamics simulations and directly gives an idea of how strongly the neutron radiation will affect the material for the considered reactor design. Step 3: Realization of a ML algorithm able to predict details of the PKA spectrum directly from the reactor parameters. In order to achieve this target the output data of the Step 2 (the PKA spectrum) and the Input data of the step 1 (reactor parameters) will be used to train the ML algorithm. Finally, the candidate will start a study on the transient effects of the energy deposited from the high energy particles on the electronic properties and current transport performance of the superconducting material using a finite element modelling approach to investigate the effects on the superconducting condensate at the mesoscale and on time scales of the order of the electron-electron and electron-phonon interaction.

Skills and competencies for the development of the activity	Multi-physics FEM simulation; Monte Carlo simulation; physics of superconductivity