# Physics of Nuclear Energy

## (9 credits)

***Objectives:*** Provide the students of Energy Engineering with the basis to understand and take part in the use of nuclear energy for peaceful purposes through fission and fusion processes.

***Prerequisites:*** Three-year degree in Ingegneria Energetica, Ingegneria Industriale o Ingegneria Medica.

***Syllabus:***

***Introduction***. Structure of atoms and nuclei, mass spectrometer, isotopes, neutrons. Cross section. Elements of statistical mechanics.

***Experimental evidences of quantum mechanics.*** Black-body radiation, absorption and emission spectra, Bohr atom, photoelectric effect, photons, Compton effect, electron diffraction, mass-energy relation, elements of special relativity, wave-particle duality, undulatory properties of matter, De Broglie relations.

***Theoretical basis of quantum mechanics.*** The time-dependent Schrödinger equation. Physical meaning of the wave function. Time-independent Schrödinger equation. Stationary states. Heisenberg uncertainty principle. Solution of the time-independent Schrödinger equation for specific relevant cases: free particle, potential well, potential barrier (tunnel effect).

***Nuclear phenomena and their interpretation***. Mass defect, binding energy, nuclear models, reaction energy, elastic collisions, binding energy per nucleon, fission and fusion.

Natural radioactivity and transmutations, radioactive decays and half-life, radioactive families, secular equilibrium, examples of nuclear relations involving neutrons and alpha, beta and gamma particles, neutron-induced activation, activity, dose and other radiometric units. Nuclear decay heat, radiation damage.

Interaction between neutrons and matter, slowing-down of neutrons, neutron cross-sections, mean free path, flux, fluence and other quantities. Transport equations (Boltzmann).

***Nuclear fission***. Fission reaction, reaction chain, characteristic time, criticality, prompt and retarded neutrons, fission reactor, fissile and fertile material, principles of fission reactor operation, enrichment, depleted Uranium, moderator and coolant, poisoning, biological shield, reflector, reactor models, Boiling Water Reactor (BWR), Pressurized Water Reactors (PWR), CANDU reactors, fission reactors in operation and under construction, nuclear wastes, nuclear safety.

***Nuclear fusion***. Fusion reaction, fusion reactor, deuterium-tritium cycle, magnetic confinement, principles and examples: JET and ITER. The European Fusion Roadmap. Elements of inertial confinement.

Classification of plasmas, Debye length, collisions between charged particles, collisional slowing-down, plasma resistivity.

Fusion reactor scheme, power balance, Lawson criterion, ideal ignition temperature, determination of the working point of a fusion reactor.

Charged particle motion in weakly inhomogeneous electric and magnetic fields. Drift velocity. Confinement in toroidal equilibria. Rotational transform. Axisymmetric and non-axisymmetric equilibrium configurations. Tokamak and stellarator.

Elements of electromagnetism. Static mgnatic fields. Equilibrium of an axisymmetric toroidal equilibrium configuration. The Grad-Shafranov equation. Plasma current induction. Transformer. Magnetic flux balance. How to determine the size of a fusion reactor.

Heat and fusion ashes exhaust. Simplified models for the plasma dynamics in the scrape-off layer. The plasma-wall interaction. The divertor.

Blanket for the tritium production and the neutron shielding. Numerical methods for the neutron transport equation. Monte Carlo method. Calculation of activation, transmutations,

***Supporting materials:***

Supporting materials distributed at the lectures. Notes from the lectures.

***Texts:***

F. Romanelli *Plasma Physics and Engineering* Nuclear Energy Encyclopedia Steven Krivit (Editor) ISBN: 978-0-470-89439-2 August 2011

***Examination:***

There are a written and an oral test. A minimum mark of 18/30 must be obtained in both the tests.