UNIVERSITÀ DEGLI STUDI DI PALERMO

DEPARTMENT	Ingegneria
ACADEMIC YEAR	2023/2024
MASTER'S DEGREE (MSC)	ENERGETIC AND NUCLEAR ENGINEERING
SUBJECT	NUCLEAR FUSION REACTORS
TYPE OF EDUCATIONAL ACTIVITY	B
AMBIT	50367-Ingegneria energetica e nucleare
CODE	23141
SCIENTIFIC SECTOR(S)	ING-IND/19
HEAD PROFESSOR(S)	DI MAIO PIETRO ALESSANDRO — Professore Ordinario — Univ. di PALERMO
OTHER PROFESSOR(S)	
CREDITS	6
INDIVIDUAL STUDY (Hrs)	96
COURSE ACTIVITY (Hrs)	54
PROPAEDEUTICAL SUBJECTS	
MUTUALIZATION	
YEAR	2
TERM (SEMESTER)	2° semester
ATTENDANCE	Not mandatory
EVALUATION	Out of 30
TEACHER OFFICE HOURS	**DI MAIO PIETRO ALESSANDRO** Monday 10:00 11:00 Dipartimento di Energia, Ingegneria dell'Informazione e Modelli Matematici - Edificio 6 - I Piano - Stanza 115 Wednesday 10:00 11:00 Dipartimento di Energia, Ingegneria dell'Informazione e Modelli Matematici - Edificio 6 - I Piano - Stanza 115 Friday 10:00 11:00 Dipartimento di Energia, Ingegneria dell'Informazione e Modelli Matematici - Edificio 6 - I Piano - Stanza 115

DOCENTE: Prof. PIETRO ALESSANDRO DI MAIO

PREREQUISITES	Knowledge of fundamentals of: - integral and differential calculus - classic physics - electromagnetism - gas kinetic theory - fundamentals of nuclear engineering - heat, momentum and mass transfer
LEARNING OUTCOMES	KNOWLEDGE AND UNDERSTANDING At the end of the course, the student will have gained an appropriate level of knowledge and understanding about the following topics: - Nuclear fusion reactions, plasmas, cross sections, reaction rate, reaction parameter - Collisional processes, Debye effect, bremsstrahlung and cyclotron radiation - Mathematical-physics models for the description of plasma dynamic - Dynamics of plasma particles and energy - Energy analysis of a plasma, break-even, ignition and relevant Lawson criteria - Plasma inertial confinement - Plasma magnetic confinement, motion of a charged particle in a magnetic field, magnetic mirrors, TOKAMAK and Stellarators - Tritium dynamics in a fusion power reactor - Technological issues related to the exploitation of nuclear fusion reaction on an industrial scale and main plant concepts The evaluation will be done through oral examination. APPLYING KNOWLEDGE AND UNDERSTANDING At the end of the course, the student will have gained an appropriate level of knowledge and understanding applied on the following topics: - Study of the particle dynamics of a D - T plasma through a lumped parameter model - Study of the energy dynamics of a D - T plasma through a lumped parameter model - Analysis of the performance of an open-type magnetic confinement system - Analysis of the performance of a TOKAMAK closed-type magnetic confinement system - Study of the tritium dynamics in a nuclear fusion power reactor The evaluation will be done through oral examination. MAKING JUDGMENTS At the end of the course, the student will have gained an appropriate level of independent evaluation on the following topics: - Understanding of technical and design reports relevant to high-energy systems - Particle and energy dynamics of a D-T plasma - Assessment of the performance of high heat flux components and breeding blankets of fusion reactors - Assessment of tritium inventory in a nuclear fusion power plant COMMUNICATION SKILLS At the end of the course, the student will have gained an appropriate level of familiarity with the technical-scientific language used in high-energy system engineering, with specific reference to nuclear fusion ones. The evaluation will be done through oral examination. LEARNING SKILLS The student will develop the ability to learn the scientific and technological issues that characterize the design and development of the most significant nuclear fusion reactor components. The evaluation will be done through oral examination.
ASSESSMENT METHODS	The final evaluation is based on an oral exam evaluated in thirty. The minimum grade to pass the exam is 18/30. The exam lasts 40 to 50 minutes and consists of an interview, divided into at least three open-ended questions concerning the whole program of the course. It is aimed at verifying: - the level of knowledge, understanding and grasp of the course content (50% of final evaluation); - the ability to apply with independent judgment and methodological rigor knowledge and skills acquired to the analysis and solution of typical issues (30% of final evaluation); - the correct use of language and the clarity (10% of final evaluation); - the ability to critically revise the acquired concepts, placing them in the appropriate logical connection with the various issues addressed in the course and in those related to it (10% of final evaluation). EVALUATION METRICS

	- 30 - 30 cum laude (excellent): excellent knowledge and mastery of the course content illustrated with full language skills and clarity, strong aptitude to apply with independent judgment and methodological rigor skills acquired recasting them critically. - 27 - 29 (distinguished): full knowledge of the course content illustrated with language skills and clarity, ability to apply with good independent judgment and methodological rigor skills acquired. - 24 - 26 (good): good knowledge of the course content illustrated with language skills, modest aptitude to apply with a good autonomy skills acquired. - 22 - 24 (satisfactory): satisfactory knowledge of the main contents of the course illustrated with acceptable technical language, poor level of autonomy in the application of acquired skills. - 18 - 21 (sufficient): minimal knowledge of the essential contents of the course and of the relevant technical language, poor quality or no autonomy of application of acquired skills.
EDUCATIONAL OBJECTIVES	The course aims to provide an overview of the major engineering issues related to the operation and development of nuclear fusion reactors, analyzing their main components as well as their functions and loading conditions. The attention will be focused on the main hypothesized nuclear fusion reactions for the development of reactors on an industrial scale and on their relevant energy features. It will be introduced the concept of plasma as the fourth state of matter, and there will be defined the main mathematical-physics variables that allow the characterization of its behavior, such as the distribution functions of particle species, the absolute temperature as well as the reaction rate and parameter. There will be examined the main collisional processes between charged particles in a plasma, introducing the concept of Debye length and the attention will be put on the emission of bremsstrahlung and cyclotron radiation. It will proceed to the development of plasma kinetic models and of plasma fluid models, focusing the attention onto a simplified lumped parameter model of a homogeneous and uniform plasma, which will be applied to the case of a D-T plasma, allowing its particle and energy dynamics to be studied. Finally, the concepts of break-even and ignition will be introduced and their relevant Lawson criteria will be derived. Subsequently, attention will be focused on the plasma confinement and related methodologies, with particular reference to magnetic confinement, in which case the motion of a charged particle in an electromagnetic field in the presence of external fields will be studied, highlighting the drifts and invariants of motion. There will be analyzed the characteristics and stability of both open and closed magnetic confinement systems, with particular attention to the magnetic mirrors and the TOKAMAK machines. Subsequently, the main components of a TOKAMAK reactor, such as the magnets, the blanket and the high flux components will be studied, together with plasma-wall interactions and tritium dynamics in a nuclear fusion reactor.
TEACHING METHODS	The teaching activity is articulated in frontal lessons and computational exercises, mainly carried out by means of mathematical software tools.
SUGGESTED BIBLIOGRAPHY	- T. Dolan, Fusion Research – Vol. I-III, Pergamon Press, 1982, ISBN-10: 0080255655 - Harms et alii, Principles of Fusion Energy, World Scientific, 2000, ISBN: 9812380337 - F. Chen, Introduction to Plasma Physics and Controlled Fusion, Plenum Press, 2015, ISBN: 9783319223087

SYLLABUS

Hrs	Frontal teaching
2	Nuclear fusion reaction - Notes on nuclear fusion reaction dynamics - Threshold energy - Cross section
5	The plasma - Distribution function and volumetric density of a particle species - Factorized and Maxwellian distribution functions - Average values of plasma characteristic variables and kinetic temperature - Reaction rate of an interaction between particle species of a plasma - Reaction parameter: general definition, physical meaning and comparison with the cross section
6	Collisional processes of charged particles - Cross section of elastic scattering - Debye effect - Bremsstrahlung and cyclotron radiation
2	Kinetic model of a plasma - Scope and application limits - Boltzmann transport equation for a generic particle species of a plasma - Discussion of Fokker-Planck and Vlasov particular forms for a non-collisional plasma - Coupling with the Maxwell's equations and with closure equations
3	Fluid-dynamic model of a plasma - Scope and application limits - Mass, momentum and energy equations for a generic particle species of the plasma - Coupling with Maxwell's equations and the equations of state
3	Dynamic model of a homogeneous, uniform and isotropic plasma - Derivation of continuity and energy equations for a generic particle species of the plasma - Particles and energy confinement time
2	Energy analysis of a plasma - Plasma heating methods - Plasma cooling processes - Energy amplification factor - Ignition and break-even conditions and related criteria
1	Plasma confinement - Gravitational, inertial and magnetic confinement

SYLLABUS

Hrs	Frontal teaching
4	Magnetic confinement - Motion of a charged particle in a field of Lorentz’s forces - Larmor radius and cyclotron frequency - Drifts of a charged particle subjected to a field of Lorentz’s forces, varying in magnitude and / or direction, and to a field of external forces - Motion invariants of a charged particle
3	Open magnetic confinement systems: principles, loss of cone, confinement efficiency - Instability phenomena - Theta and zeta "magnetic pinch" systems and related type of instability phenomena of "sausage" and "kink" type
3	Closed magnetic confinement systems: principles - Rotational transform and Kruskal-Shafranov stability criterion - TOKAMAK machine: principles and mode of operation, confinement efficiency and instability phenomena - Stellarators machine: principles and mode of operation
3	Main TOKAMAK reactor components: magnets, blanket and high flux components - Plasma-wall interactions and effect of impurities
1	Conversion processes and tritium breeding in a nuclear fusion reactor - Models for tritium dynamics - Tritium breeding
1	International programme for R&D on nuclear fusion - JET, ITER and DEMO reactors - IFMIF

Hrs	Practice
3	Distribution function of plasma particle species - Kinetic temperature - Reaction rate - Reaction parameter
3	Dynamic model of a homogeneous, uniform and isotropic plasma: application to the study of particle and energy dynamics of a D-T isothermal plasma
3	Analysis of the motion of ions and electrons in a field of Lorentz’s forces
3	Evaluation of the containment efficiency of open and closed magnetic confinement systems
3	Assessment of tritium breeding for a nuclear fusion power reactor