Educational goals for an EU Master in Fusion Science and Technology

FuseNet
The European Fusion Education Network
ASSOCIATION

1. Preface

The aim of the Fusion master certificate is to generally increase the level of fusion education at the master level and create a common ground in Europe, to increase the attractiveness of the specialization 'fusion' for students, as well as to establish the 'fusion master' as a recognized brand, a mark of high quality.

The criteria are designed to set a high standard. Rather than taking the lowest common denominator of existing fusion curricula, or to remove specificities that can be associated with locally developed schools and centers of excellence, the criteria should guarantee a high level of the fusion master, thereby realizing an added value to the existing educational programs.

The multi-disciplinary character of plasma physics and fusion should lead to a large spectrum of knowledge and applications, but it should not prevent a clear-cut affiliation to a departmental structure within the local academic systems. Graduates of such programs should naturally be prepared to a holistic approach, which in turn would encourage a strong awareness of societal needs and boundary conditions.

2. Academic Criteria

This approach led to the definition of the following parameters of the curriculum:

1. Total volume: at least 48 ECTS, of which at least 24 corresponding to academic work, and at least 24 to the Master thesis projects.

   Of the former, a reference scheme can be that 8 ECTS could come from the core program, 8 from the advanced program and 8 from more practical laboratory/internship work. Note, however, that part or, in some cases, all of the credits for the more advanced topics could be obtained through laboratory/internship work.

2. Core program: to cover material that can be grouped in four blocks (about 8 ECTS)
   a. Fundamentals;
   b. Macroscopic description of plasmas in fusion devices;
   c. Plasma dynamics and waves for heating and diagnostics;
   d. Fusion technology;
   e. Plasma physics outside direct fusion applications.

3. Advanced elective program (about 8 ECTS) to be selected from a broad range of topics, loosely divided into
   a. Physics oriented curriculum
   b. Engineering oriented curriculum

4. Master thesis work, resulting in a Master thesis which represents original scientific work (at least 24 ECTS)

With this structure, the criteria guarantee the required academic level, while leaving sufficient flexibility for the universities to design a curriculum that does justice to the local strengths and educational culture.

By training the students in the international, multidisciplinary research environment of fusion, the fusion master will acquire – next to the specific academic core knowledge and generic academic and technical skills – the following more generic competences:

1. Awareness of societal value of his/her research
2. Ability to work in a multidisciplinary, international research environment
3. Ability to work in a problem-driven, goal-oriented fashion
4. Communicate scientific results orally and written, in English

With this set of knowledge and competences, the fusion master will not only be excellently prepared for a career in fusion research, but also for a career outside this field, e.g. in innovative, high-tech industry.

Below we specify guidelines for this common knowledge, providing an estimate for the equivalent ECTS credits for different blocks. These blocks do not necessarily correspond to courses, but rather to areas of knowledge that should have similar relative weights. In addition, for the advanced topics, a large degree of flexibility should be applied, as part of this knowledge can be acquired though laboratory (internship) projects, without necessarily formal ex-cathedra teaching. The list of elective subjects should be considered by no means exhaustive or exclusive.

2.1 Topics of which a EU Master student should have solid knowledge (total of at least 8 ECTS).

Block 1 – the fundamentals

- Basics of thermonuclear fusion
- Specificities of magnetic vs. inertial fusion
- The plasma state and its collective effects
- Charged particle motion in electric and magnetic fields
- Collisions, plasma resistivity and relaxation phenomena

Block 2 – macroscopic description of plasmas in fusion devices

- Two-fluid and single-fluid MHD models
- Macroscopic plasma equilibrium and stability
- Magnetic confinement
- Basic properties of tokamaks and stellarators

Block 3 – plasma dynamics and waves for heating and diagnostics

- Basic aspects of waves in magnetized plasmas
- Fundamentals of wave-particle interactions
- Exchange of energy between waves and particles
- Basic micro-instabilities

Block 4 – Fusion technology

- Basic design aspects of a fusion reactor
- Confinement and transport
- Plasma heating and current drive
- Elements of material science for fusion
- The basic problems of plasma-wall interaction

Block 5 – plasma physics outside direct fusion applications

- Basic problems in plasma astrophysics
- Basic problems in plasma space physics
- Basic plasma industrial applications

2.2 Topics of which a EU Master student should have *some* knowledge (total of at least 8 ECTS)

2.2.1 Physics oriented curriculum

- Advanced treatment of Vlasov equation
- Fokker-Planck collisional terms
- Kinetic description of plasma waves
- Waves in a hot magnetized plasma
- Non-linear effects in plasmas
- The tokamak
- Plasma diagnostic techniques
- Plasma heating by neutral beams
- Plasma heating by EC, IC and LH waves
- Alfvén waves
- The burning plasma regime
- The Stellarator and other confinement schemes of potential for a fusion reactor
- Elements of plasma-wall interactions (including plasma fuelling and particle control)
- ITER and DEMO

2.2.2 Engineering oriented curriculum

The construction, maintenance and operation of fusion devices require mastering of many branches of engineering. The proposed curriculum should train students to understand and develop related technologies. Below we list topics that could typically be covered.

- Materials in extreme environments
- Cryogenics and superconductivity, vacuum techniques
- High Power Microwaves: Generation and Transmission
- The magnet system of a fusion device
- Vacuum vessel and in-vessel components (Limiters, Divertor design)
- Engineering aspects of Neutral Beam Injection
- Technology of ion cyclotron and lower hybrid wave heating and current drive systems
- Fusion plasma diagnostics
- Fuel cycle and breeding blanket
- Robotics: Manipulators and Remote handling systems
- Nuclear safety; nuclear fission plants
- Plasma control theory and technology
- Computational engineering
- General problems in energy production
- Energy storage; electrical grids

2.3 Required work in Master thesis (total of at least 24 ECTS)

The Master thesis should represent an original piece of research work directly related to fusion plasma physics or engineering or to fusion and nuclear energy, or having potential applications in fusion physics and technology. The originality can reside in the experimental or theoretical/numerical methods adopted to solve a particular problem, if not in the final physics results. The student should be exposed to a professional research group, and should be able to situate his/her own specific activity within a global framework.

2.4 Required know-how, achieved directly in laboratories (internships), or ad hoc seminars

Through the academic classes and the Master thesis work, the student should have developed a qualitative overall view of the fusion science and technology and plasma physics field, with a specific, more quantitative expertise in a sub-field. He/she should be familiar with at least one set of experimental techniques (such as plasma diagnostics, plasma control, data acquisition), and /or one set of theoretical techniques (such as an analytical expansion method).

He/she should also have a solid knowledge of the fundamentals of numerical methods for the solution of physics and/or engineering problems. The student should also be ready to be integrated for his/her PhD into a research team, with which to communicate and exchange ideas.

The student should be at ease with writing a scientific manuscript in English, and communicate orally the results of a project. Finally, the student should be sensitive to the societal value of his/her research, and be ready to undertake problem driven, solution-oriented research and development.