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Fusion Education in the European Union

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Recent educational initiatives are outlined aiming to maintain the expertise that has placed the EU Fusion Programme at the forefront of international fusion research and engineering, and to ensure the availability of competent staff to construct and operate ITER and DEMO.

Keywords: education, EU fusion programme, Erasmus Mundus European Master, Fusion Education Network, human resource management, ITER, DEMO

1 Introduction

Fusion research is entering a new phase. The construction of ITER, the Broader Approach activities, and the preparation for DEMO require an expansion of the fusion programme and a shift of the emphasis from plasma physics to engineering and nuclear materials. There is also a growing need for competences on nuclear project related issues such as project management, nuclear licensing, quality assurance, risk assessment, and management of procurement processes, as well as a need for stronger collaboration with industry. Even within the fundamental plasma physics research there are important shifts of emphasis.

In Europe, research in the field of nuclear fusion by magnetic confinement is strongly integrated by EURATOM. There are no national research programmes in the strict sense. The EU programme is executed by more than 20 institutes associated with EURATOM (called Associations for Fusion). The large majority of EU countries plus Switzerland have signed Association contracts. A more specific working framework EFDA (European Fusion Development Agreement; www.efda.org) has been established for the exploitation of the largest fusion experiment in the world JET (Joint European Torus) and for technological developments necessary for future fusion installations. The EU fusion programme, a prototype of integrated European research, has maintained a complementarity of programmes and installations. This strongly integrated organization is at the origin of the dominating position of Europe in magnetic confinement fusion (MCF) research and of the decision to build the next step large international installation ITER in Cadarache.

In order to maintain the expertise that has placed the EU fusion programme at the forefront of international fusion research and engineering, and to ensure the availability of competent staff to construct and operate ITER and DEMO, a long-term Human Resource Management plan for the European Fusion Programme is needed, which should reflect the increase of the volume of the programme, the shifts in required competences, and the natural aging of the present population of professionals in the fusion community. It is estimated that at least 40 new researchers should come into the system each year.

A key element of this human resource strategy is a well-planned programme for education in fusion science and engineering, to make sure that a match between the required competences and the available professionals is realised, and that a sufficient number of new people enter the fusion system. In the framework of the Bologna declaration there is furthermore the need to harmonize advanced fusion education, training and professional qualification, and to strengthen interaction and exchange of academic resources in the European Research Area.

Fusion education is a field that lends itself by excellence for European collaboration, as it can build on the very well developed collaboration between the EURATOM Associations through the EFDA agreement. Coordinating fusion education across Europe allows the joint development of common educational goals and standards, high quality educational materials, and easy access to hands-on experiments and experimental facilities throughout Europe. A special role is played by the Joint European Torus JET, exploited jointly by the European researchers under the EFDA coordination, which as a joint European facility is a particularly inspirational environment for education and training.

Presently, the following activities exist in the field of fusion training and education in the EU:

- Mobility Scheme (starting usually from Post-Doc level)
- National schemes and fellowships by the associated laboratories
- European PhD in Fusion Science and Engineering
- European Training Scheme for ITER: selected laboratories offer posts on key topics for ITER R&D
- Erasmus Mundus Master in Nuclear Fusion Science & Engineering Physics
- EU CSA (Coordinated Support Action) << Fusion Education Network >>- FUSENET

The last two initiatives will be outlined below.

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2 Erasmus Mundus " European Master in Nuclear Fusion Science & Engineering Physics " (FUSION-EP)

The European Master in Nuclear Fusion Science and Engineering Physics (**FUSION-EP**) is offered by the following partners:

- Universiteit Gent, Belgium (coordinator)
- Université Henri Poincaré, Nancy, France
- Kungliga Tekniska Högskola (KTH) Stockholm, Sweden
- Universität Stuttgart, Germany
- Universidad Complutense de Madrid, Spain
- Universidad Carlos III de Madrid, Spain
- Universidad Polytécnica de Madrid, Spain

The ITER host country France is also member of the present Erasmus Mundus consortium. All the partners have a long relationship in the framework of the coordinated EURATOM research programme on nuclear fusion, guaranteeing a strong synergy and visibility. The aim of the Masters programme (**http://www.em-master-fusion.org**) is to provide a high-level multinational research-oriented education in fusion-related engineering physics, in close relation to the research activities of the partners, and with a well-integrated language and cultural experience. The combined and harmonized teaching &research of the 7 universities offers a far greater variety of competences in the field of fusion science and engineering physics than could be provided by each of the single universities, and therefore guarantees a significant added value for the students in terms of specialisation opportunities. The Joint European Master Programme offers a genuine European opportunity for Master level studies in a field which is of crucial importance to contribute to the solution of the ever more urgent and vital problem of world energy supply. A large number of scientists and engineers will be required in two main categories: " Fusion technology and engineering physics " and " Plasma physics " and their formation takes typically 10 years, requiring a structured European Master level education. Furthermore, fusion research shows an increasing and very important spin-off in many fields of science and engineering, such as new materials, nanotechnologies, superconducting coils, robotics, electronic components, high power RF sources, space propulsion. The EU framework described in offers many possibilities for summer schools and doctoral studies.

The studies in engineering physics are devoted to the technical applications of physics and strongly supported by the research activities in the different laboratories within the Consortium. By combining in a balanced way the basic concepts of a degree in engineering with the essentials of an education as a engineering physicist, these studies seek to train engineers capable of performing or leading technical and scientific research in universities, research establishments or industry.

The engineering component of the studies makes the physics engineer familiar with the analysis, design and optimization of new and existing systems, products, machines, materials, etc., in which simplification to manageable system descriptions (from rules of thumb to expert systems) is essential. In the physics component the reductionist approach holds centre stage; here experiments and mathematical modelling seek to reduce physical phenomena to their very essence and to discover the physical laws applicable. Even though the approach has a more philosophical slant, the rigorous attitude is essential and a physical theory should stand a validation by experiment.

Physics engineers are trained, first and foremost, for R&D purposes. Their wide-ranging education makes them fit for all companies and research establishments where interdisciplinary R&D requires in-depth knowledge of physics. They will constitute a substantial percentage of the large number of additional researchers required for the establishment of the EU as the best centre of excellence in the world. Both components of the studies especially qualify the physics engineer to fill executive jobs at a later stage.

In view of the expertise of the partners, the programme offers three programme tracks to the student: (i) Plasma physics (fusion-oriented); (ii) Computational methods in physics; and (iii) Instrumentation and Radiation. The programme structure is combined with a mandatory stay of the student at three universities in three countries: semesters1&2 at University A; semester 3 at B and semester 4 (Master thesis) in C. Semesters 3&4 are in a particular track. After semester 2 a summer event is organized in which the tracks and Master thesis topics are proposed. Student mobility is an inherent part of the programme structure and philosophy.

The admission criteria are: a bachelor degree in engineering physics, applied physics, physics or equivalent degrees. Sufficient bachelor level knowledge in classical and modern physics is mandatory together with the necessary mathematical and computer programming skills. No difference is made between third-country students, EU students, grantees and non-grantees. Applicants (students and scholars) from third countries (applying for a grant or not) will be subject to a well defined selection procedure aiming at high quality.

3 Erasmus Mundus International Network for Nuclear Fusion Education

For collaborations outside Europe, EURATOM establishes bilateral agreements, which are privileged channels for the Associations and institutes outside Europe. Global collaborations have been established in the framework of IAEA (International Atomic Energy Agency) and IAE (International Energy Agency). Collaborations are formalized in

the form of IAEA CRP 's (Coordinated Research Projects) and IAE Implementing Agreements. IAEA has provided the legal framework for the development of ITER since 1988. All the partners are involved in CRP 's and Implementing Agreements, and thus have privileged links with non-EU universities and research institutes. Furthermore, several FUSION-EP partners have close collaborations with NIS (New Independent States) institutes and universities in the framework of INTAS.

The European thinking about fusion R&D emphasizes an integrated and strongly coordinated approach which has resulted in the leading position of the EU in magnetic confinement fusion (MCF). The European Master in Nuclear Fusion Science and Engineering Physics - Erasmus Mundus programme (FUSION-EP) offers the opportunity to study this European vision on MCF R&D in Europe and to experience the diversity in its approaches and applications. Therefore, in addition to the FUSION-EP teaching and exchange programme, a new partnership has been established between the FUSION-EP Consortium and a number of high level key Third Country -institutions specialised in fusion research and education. The general objective of this network is to build and strengthen a worldwide network of EU and non-EU based centres of excellence in fusion R&D studies. The FUSION-EP Consortium - itself a partnership of renowned European institutes of research and training in fusion - aims at brokering an improved connection and coordination between different key non-EU institutions within its network range, in view of collaboration between EU and non-EU scientists and engineers in the international research project ITER.

Key Third Country-institutes have been selected on the basis of their competence, (inter)national network density, and longstanding links with the FUSION-EP Consortium partners. They are among the world 's most renowned and active institutes in the field of MCF studies.

- UCLA (USA)
- University of Wisconsin-Madison (USA)
- St. Petersburg State Polytechnic University (Russia)
- Moscow Engineering Physics Institute (Russia)
- University of Science and Technology of China (Hefei)
- Tsinghua University Beijing (China)
- Southwestern Institute of Physics, Chengdu (China)

The main political-economic spheres in fusion R&D (Europe, North-America, and Asia) are represented by two or three leading institutes as main network nodes. However, every institute has its own network partners downstream and thus plays a broker 's role in its own turn. It is this spirit of brokerage between different network nodes (' tertius iungens ' principle) that promises to allow for a dynamic learning network. This network brokerage between FUSION-EP and its non-EU partners can be visually imagined as a hub-and-spokes-model, with the FUSION-EP Consortium in the middle connecting different previously disconnected networks. Futhermore, all the countries involved are members of the large scale international research project ITER, and within these countries the partner institutions are main players.

The specific objective of this new partnership is to intensify the exposure and interaction of FUSION-EP institutes with non-EU fusion R&D approaches and education in the rest of the world. The interaction in this new partnership modality is being realized through outgoing mobility of EU students and scholars on the one hand and joint reflection and analysis seminars on the other hand. This interaction is deemed crucial to better adapt the FUSION-EP curriculum to non-EU students. Exposure of EU students and scholars to institutes in Third Countries is critical for a better understanding of the teaching needs of non-EU students with reference to the European model of fusion R&D. It also enhances the understanding of fusion R&D problems and solutions in Third Countries and thus allows for the integration of interesting approaches and practices from other regions in the teaching activities of the FUSION-EP.

The interaction will also increase the specialized knowledge on specific characteristics of fusion R&D in the hosting countries and thus contribute to more targeted future research and teaching collaboration. This new partnership will also allow the assessment of teaching plans/methods in the partner institutes with the aim to develop mutual standards and facilitate the future exchange between education institutes (e.g. by better preparation of Bachelor students wanting to follow the FUSION-EP). Through the exchange of students and in particular scholars we also want to strengthen the general interaction among EU and non-EU countries with respect to research, exchange of practices and policies of fusion R&D.

Finally, through this cooperation an increased outreach of FUSION-EP is envisaged. Firstly, by establishing reference institutes for future non-EU FUSION-EP students in different parts of the world. Partner institutes can not only distribute information on the FUSION-EP in their country or region, but also serve as information centres for students of that part of the world searching for more detailed information about the study programme of the FUSION-EP, the specific required skills (by e.g. the organisation of short preparatory courses in the partner institutes, $\cdots$). Partner institutes become in that way information and pre- selection antennas for the FUSION-EP. All this must help to increase the quality of the FUSION-EP programme. Secondly, offering the possibility to complete short training periods in non-EU institutes will also increase the appeal of the FUSION-EP programme to EU students. This Erasmus Mundus programme enforces the intercultural exchange among EU and non-EU students, sparks the interest to know the other countries better, and enhances mutual understanding and cooperation.

4 FUSENET

The European Fusion Education Network (FUSENET) for education in fusion science and technology started in October 2009, as part of a comprehensive package of coordination actions, in order to increase, enhance, and broaden fusion training and education activities in Europe. FUSENETconsists of eleven focussed work packages, with a total budget of 2.0 M€. The project brings together a broad representation of the European fusion community with 35 participants from 18 countries, of which 22 Universities and 13 EURATOM Associations. The FUSENET project will cover all education levels, from secondary school through Bachelor and Master level, to PhD.

The specific objectives of the FUSENET project are:

1. The sustainable establishment of the FUSENET Association, which provides a permanent platform for the coordination of existing actions, the initiation, development and execution of new EU-wide actions, and for the exchange and dissemination of information.
2. A coherent programme of EU-wide learning opportunities in the fusion programme and related industry, with jointly developed educational goals for different target groups, which is easily accessible and transparent through the central FUSENET website.
3. High quality teaching materials and hands-on experiments, which are used throughout Europe to create highly attractive and effective learning opportunities, and which lead to more coherence in the level and scope of knowledge of students.
4. A mobility system in which the best learning opportunities are available to students throughout Europe, and which leads to the forming of many interpersonal links among people in the fusion system.

The actions of FUSENET build upon the already strongly integrated European Fusion Research programme, coordinated under EFDA. The experimental facilities and research groups in this programme will play a major role in the educational programme, and optimizing the accessibility of those facilities for students is an important goal of FUSENET. A special role is played by the Joint European Torus JET, exploited jointly by the European researchers under the EFDA coordination, which as a joint European facility is particularly inspirational as a place for education and training.

The network will be given a permanent identity by the establishment of the FUSENET Association, which will provide a platform for the coordination of existing actions, the initiation, development and implementation of new EU-wide actions, and for the exchange and dissemination of fusion education information.

The envisaged concrete end result of the FUSENET project is an integrated fusion education system in Europe, with strong links between fusion institutes and higher education institutes. Through a central website, the programme will offer a transparent structure of coherent educational actions, accessible and inviting, in which students and teachers can easily find their way to a variety of attractive ways to participate in the fusion research programme.

The strategy of the work plan is directly connected to the goal of a broad base of knowledge transfer to secondary school and bachelor/master/technical students, and a high peak of PhD students. This leads to actions aimed at all levels of fusion education. There are three main elements to the strategy:

1. **Critical mass.** As the number of students in fusion subjects in most countries is not large enough to support specialised Master or PhD degrees, actions need to be coordinated and initiated on a European scale, in order to reach sufficient critical mass.
2. **Coherence.** To optimise the flow of students through the system, better links are needed between the different education layers. This means both a focus on secondary school teachers and good connections between higher education institutes and fusion institutes.
3. **Transparency.** Learning opportunities need to be more accessible to students across Europe, through dissemination of information, and improvement of mobility. The educational goals of bachelor/master and doctoral level courses need to be more aligned, to make it easier for students to navigate the fusion system.

The European Fusion Education programme should be considered as the natural counterpart of the European Fusion Research programme, coordinated under the EFDA agreement. The two will work in close harmony and the synergy will be obvious. The ultimate aims of the educational programme are the support of the fusion programme, either directly by training high level researchers, or indirectly by improving the rooting in society. More directly, FUSENET will contribute significantly to the coordination of high-quality research, because it

- enhances the participation and exchange of students and their teachers in the fusion programme,
- stimulates the creation of attractive student training opportunities,
- further strengthens the ties between research groups

To make the network sustainable, an association (the FUSENET Association) will be set up with the task to manage and further develop the network formed under the CSA. The organization of the network and its embedding in an Association is similar to that of the European Nuclear Energy Network (ENEN).

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