EUROPEAN MASTER IN NUCLEAR ENERGY (EMINE). WHEN ACADEMY AND INDUSTRY MEET

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ABSTRACT

EMINE master programme is an international education initiative offered by KIC-InnoEnergy under the framework of the European Institute of Innovation and Technology (EIT). Students in the programme have the opportunity to acquire an in-depth knowledge of the nuclear industry, through unique and specialised courses covering a wide range of subjects. Students choose between UPC (Barcelona) and KTH (Stockholm) for the first year and between Grenoble-INP and Paris-Saclay University (France) for the second year. Grenoble École de Management (GEM) completes the list of academic partners: students take a 3-week summer course on energy management issues after their first year in EMINE. EMINE students also benefit from the involvement of our industrial partners (AREVA, EDF, ENDESA, INSTN-CEA, and Vattenfall) in the Programme. For the academic institutions, EMINE is the opportunity to provide a high level education aligned with the industrial needs. The international collaboration among universities helps improving the quality and the adoption of best practices. EMINE attracts good students to our centres whereas the EIT funding and the industrial involvement allows a number of activities that otherwise would have been difficult to carry out, such as the assistance of external industrial experts or field activities. MSc EMINE helps tomorrow's nuclear engineers take up the challenges the nuclear energy industry faces in terms of safety, social acceptability and waste management. By offering outstanding technical training and addressing the economic, social and political aspects of nuclear energy, the programme broadens the scope of traditional nuclear education.

1. Introduction

The European Master in Nuclear Energy, now running its 5th edition, is an international education initiative offered by KIC InnoEnergy under the framework of the European Institute of Innovation and Technology (EIT).

EMINE helps tomorrow's nuclear engineers take up the challenges that the nuclear energy industry faces in terms of safety, social acceptability and waste management. By offering outstanding technical training and addressing the economic, social and political issues of nuclear energy, this MSc programme broadens the scope of traditional nuclear education.

The uniqueness of EMINE lies in the strong involvement of its industrial partners. Four major players in nuclear energy – AREVA, EDF, ENDESA and Vattenfall – take active part in the

programme. CEA, and its educational body, INSTN, actively contribute to teaching activities which allows EMINE to benefit from the expertise of one of the most important research centres in nuclear energy in Europe.

The master is fully taught in English and its duration is two years (120 ECTS credits). EMINE students acquire an in-depth knowledge of the nuclear industry, through a series of unique and specialised courses in the field of Nuclear Engineering, covering a wide range of subjects. In the first year students take courses at either of the following locations (see Figure 1):

- Royal Institute of Technology (KTH), Stockholm, Sweden
- Universitat Politècnica de Catalunya. BarcelonaTech (UPC), Barcelona, Spain

At the end of this first year, students from both UPC and KTH gather for a three week summer school at Grenoble École de Management. During the second year, students have the choice between 6 specialties offered by the following institutions:

- Grenoble Institute of Technology (Grenoble INP), France
- Paris-Saclay University (UPSay), France

Upon successful completion of the programme, students are awarded a double diploma from the first and second universities, as well as a certificate delivered by KIC Innonergy.

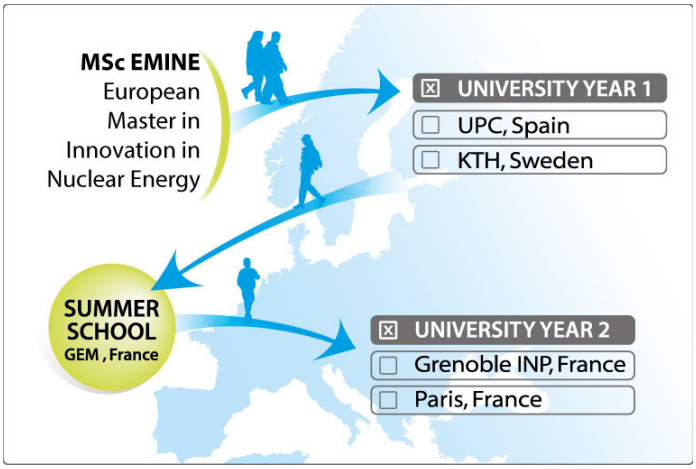

Figure 1. Mobility of students in MSc EMINE.

2. KIC InnoEnergy Master School

KIC InnoEnergy is an European company for innovation, business creation and education in sustainable energy. It is one of the so-called Knowledge and Innovation Communities created by the European Institute of Innovation and Technology (EIT)

The EIT was set up in March 2008 by the European Parliament and Council. Its mission is to:

- Contribute to the competitiveness of Europe, its sustainable economic growth and job creation by promoting and strengthening synergies and cooperation among businesses, education institutions and research organisations.
- Create favourable environments for creative thoughts, to enable world-class innovation and entrepreneurship to thrive in Europe.

The EIT strongly contributes to the objectives set out in Horizon 2020, in particular by addressing societal challenges in a manner that is complementary to other initiatives in these areas.

The EIT fully integrates the three sides of the Knowledge Triangle (higher education, research and business) by bringing together leading players from all these dimensions to cooperate within the KICs. The EIT's first three KICs were launched in 2010:

- Climate-KIC: addressing climate change mitigation and adaptation
- EIT Digital: addressing information and Communication Technologies
- KIC InnoEnergy: addressing sustainable energy

and a further two in 2014:

- EIT Health: addressing healthy living and active ageing
- EIT Raw Materials: addressing sustainable exploration, extraction, processing, recycling and substitution

KICs' activities cover the entire innovation chain, including training and education programmes, innovation projects and business incubators. Each KIC has been set up as a legal entity and has appointed a CEO to run its operations. KICs have a great degree of autonomy to define their legal status, internal organisation and working methods.

KIC InnoEnergy aims to achieve a sustainable energy future for Europe through innovation. Its mission is to build an operational framework between industry, research and higher education. The strategic objective is to become the leading engine of innovation in the field of sustainable energy.

KIC InnoEnergy is a world class alliance of top European players from Industry, Research, Universities and Business Schools (Figure 2). The Consortium consists of 27 shareholders and additional 160 associate and project partners. They are organised around six regional units, the so-called Co-Location Centres (CC): France, Benelux, Germany, Iberia, Poland Plus and Sweden.

Figure 2. Kic Innoenergy as an European network.

KIC InnoEnergy Master School is running seven Master programmes in sustainable and low carbon energy that offer a combination of engineering and entrepreneurship. All these programmes deliver high quality content, covering a range of subjects considered crucial to meeting today's global energy challenges:

- MSc RENE – Renewable Energy
- MSc EMINE – European Master in Nuclear Energy
- MSc SENSE - Smart Electrical Networks and Systems
- MSc SELECT – Environomical Pathways to Sustainable Energy Systems
- MSc ENTECH – Energy Technologies
- MSc Energy for Smart Cities – Efficient Energy for Smart Cities
- MSc Clean Fossil and Alternative Fuels Energy

All these Programmes have international mobility as a common character:

- Students take courses in two different universities and countries.
- They get a training in innovation and entrepreneurship during the summer school
- Eventually students start an internship with one of KIC InnoEnergy partners.

Top European Universities are involved in the Master School:

AGH	AGH University of Science and Technology, Poland
INP	Grenoble Institute of Technology, France
IST	Instituto Superior Técnico, Portugal
KIT	Karlsruhe Institute of Technology, Germany
KUL	KU Leuven, Belgium
KTH	Royal Institute of Technology, Sweden
UPSay	Paris-Saclay University, France
SUT	Silesian University of Technology, Poland
TU/e	Eindhoven University of Technology, The Netherlands
UPC	Universitat Politècnica de Catalunya·BarcelonaTech, Spain
UU	Uppsala University, Sweden

and two business schools:

ESADE Business School, Spain
Grenoble École de Management, France

For all admitted students from the EU/EEA, and for the best among the students from other countries, KIC InnoEnergy covers the cost of the tuition fee. KIC InnoEnergy also offers scholarships to top applicants and also covers the costs related to events integrated in the curriculum (Kick-off event, summer school, field visits, European energy fairs…).

Some key figures of the Master School are given in Figure 3.

Figure 3. Some key figures of the KIC InnoEnergy Master School.

3. Description of the EMINE programme

The master provides an in-depth knowledge of the nuclear industry. The first year EMINE, either at KTH or at UPC, students acquire a series of competencies that are required in nuclear engineering: they learn the fundamentals of nuclear engineering, nuclear safety and radiation protection; they learn as well key aspects of the design and management of nuclear power plants.

During the summer school at GEM, students have the unique opportunity to develop transversal skills and acquire competences that are generally not delivered by standard master programmes and that will help them in their professional life: ranging from Energy Economics topics to facets of the Emotional Intelligence a leader must have, and including issues like Strategy and Innovation in the Energy sector and Intellectual Property.

During the second year students choose among the following majors, the first one carried out at Grenoble-INP and the other five at Paris-Saclay University (France):

- Materials Science for Nuclear Energy
- Nuclear Reactor Physics and Engineering
- Nuclear Plant Design
- Operations
- Fuel Cycle Engineering
- Decommissioning and Waste Management

The courses that students follow in the different itineraries are listed in tables 1 to 4. Towards the end of the second year, students develop a Master thesis during their internship at an industrial or research position. The involvement of EMINE industrial partners makes it easy for the students to find a Master thesis internship.

Table 1. Course structure for the EMINE first year at KTH.

Course	Credits (ECTS)	Type
Radiation, Protection, Dosimetry and Detectors	6	Mandatory
Sustainable Power Generation	9	Mandatory
Nuclear Reactor Physics, Major Course	9	Mandatory
Nuclear Reactor Technology Nuclear power Safety	8	Mandatory
Renewable Energy Technology	6	Elective
Thermal-Hydraulics in Nuclear Energy Engineering	6	Elective
Nuclear Physics	8	Elective
Radiation Damage in Materials	6	Elective
Generation IV Reactors	6	Elective
Nuclear Reactor Dynamics and Stability	6	Elective

Table 2. Course structure for the EMINE first year at UPC.

Course	Credits (ECTS)	Type
Fundamentals of nuclear engineering and radiation protection	8	Mandatory
Systems, components and materials	6	Mandatory
Reactor Physics and Thermal Hydraulics	7.5	Mandatory
Fuel Cycle and Environmental Impact (FCEI)	5.5	Mandatory
Course Project 1	3	Mandatory
Regulations and Safety	5	Mandatory
Management of nuclear power plants	8.5	Mandatory
Course Project 2	3	Mandatory
Fusion technology	4.5	Elective
Non-destructive testing methods	4.5	Elective
Core Design	4.5	Elective
Monte-Carlo methods for radiation transport calculation	4.5	Elective
Computational Fluid-Dynamics applied to Nuclear Technology	4.5	Elective

Table 3. Course structure for the major at Grenoble-INP (EMNE 2nd year).

Course (all mandatory)	Credits (ECTS)		Location
Reactor concept and materials	6		Grenoble INP
Material ageing in nuclear environment	6		Grenoble INP
Energy and Components EDF	6		
General approach to energy issues		1	Grenoble INP
Components		5	Materials Ageing Institute (EDF)
Nuclear Fuels CEA	6		CEA Cadarache
Innovation an management	6		GEM
Internship and Master Thesis	30		

Table 4. Course structure for the five majors at Paris-Saclay (EMINE 2nd year).

Nuclear Reactor Physics and Engineering	Credits (ETCS)
Safety Introduction	2
Functional description of a power station	3
Thermo hydraulics of reactors	6
Calculation Codes for Reactors	4
Nuclear Materials	5
Introductory Nuclear Physics	6
Neutronics – Part I	4
Labworks on PWR and Other Systems	4
Neutronics 2	4
Fuel and associated cycles; Criticality-Safety; Protection and Radiation Shielding	4
Internship	18

Nuclear plant design	Credits (ETCS)
Safety Introduction	2
Functional description of a power station	3
Risk Management	5
Environment & society	5
Radioprotection 1	2
Nuclear power station materials	5
Nuclear Thermal Hydraulics	5
Applied Nuclear Physics	5
Radioprotection 2	3
Design and construction of structures and infrastructures	4
Safety design: General Architecture, Systems and Equipment	4
Control Systems	4
Internship	18

Operations	Credits (ETCS)
Safety Introduction	2
Functional description of a power station	3
Risk Management	5
Environment & society	5
Radioprotection 1	2
Installation management	5
Nuclear Thermal Hydraulics	5
Applied Nuclear Physics	5
Radioprotection 2	3
Safety and production	4
Maintenance of nuclear installations	4
Instrumentation and calculation codes	4
Internship	18

Fuel Cycle Engineering	Credits (ETCS)
Safety Introduction	2
Functional description of a power station	3
Risk Management	5
Environment & society	5
Radioprotection 1	2
Nuclear fuel and the front end of the nuclear fuel cycle	5
Nuclear spent fuel recycling	5
Radioprotection 2	3
Waste conditioning	4
Radioactive waste management and repository design	4
Internship	18

Decommissioning and Waste Management	Credits (ETCS)
Safety Introduction	2
Functional description of a power station	3
Risk Management	5
Environment & society	5
Radioprotection 1	2
Politics, strategy and management of decommissioning	5
Sanitation and environment	5
Radioprotection 2	3
Practical training and simulation of the dismantling activities	4
Methods of decommissioning	4
Waste management and decommissioning of waste	4
Internship	18

The programme thus combines science and technology with management and innovation in the energy field and leadership skills in nuclear safety. Real industrial problems are presented in the classroom to be solved by students, and engaging pedagogical methods like PBL or e-learning strategies are used so as to create a learning atmosphere that help students achieve meaningful learning. The collaboration of the Industry is essential in achieving this goal.

4. Industrial involvement in EMINE

For the nuclear industry, it is a challenge to maintain the excellence and nuclear competence in our countries in particular and in Europe, in view of the recent changes towards nuclear phase out in some countries. The strong European exchange within EMINE is clearly beneficial and has been shown very fruitful already.

EMINE students benefit from the involvement of our industrial partners in the Programme. Industrial implication in the master takes a multifaceted form:

- A large number of topics and subjects are covered directly by lecturers from industrial partners or other collaborators from industry, research centres and Regulatory Authority, either at the universities' classrooms or at the premises of the companies (EDF, CEA-INSTN, Tecnatom). The "immersion" courses organized by CEA and EDF at their facilities offer the student a unique opportunity to discover the nuclear industry and their research activities.
- EMINE industrial partners participate in the Programme Steering Board and are active members of the EMINE consortium.
- Industrial partners and collaborators organise technical visits to their facilities: nuclear power plants, heavy components factories, laboratories, full-scope and incidental simulators, La Hague fuel reprocessing plant, Georges Besse II enrichment plant, Bure deep storage site, the Vattenfall Research Laboratory in Älvkarleby (Sweden), etc.
- The industrial partners offer internship positions for the students to develop their Master Thesis.

Some of the courses with a large implication of the industry are listed below:

- Leadership for Safety in the Nuclear Energy Industry (KTH, 6 ECTS). The course is organized around the presentation and analysis of actual cases (accidents and incidents, decision situations) from which relevant lessons are to be learnt. Lectures are given by expert guest lecturers from authorities and industry.
- Elements of the Back-end of the Nuclear Fuel Cycle: Geological Storage of Nuclear Spent Fuel (KTH, 7.5 ECTS). This course is organized within the EMINE programme by the KTH, the Center for University Studies Research and Development (Nova - Oskarshamn) and by the Swedish Nuclear Fuel and Waste Management Company (SKB) and supported by the Linnaeus University and the University of Illinois at Urbana-Champaign. The unique feature of the course is that the students visit Clab (an interim geological repository for spent fuel), the Laxemar Site (study area for bedrock and surface geology), the Äspö Hard Rock Laboratory (research laboratory for geological spent fuel disposal), and the Canister Laboratory (development centre for spent fuel encapsulation technology). See figure 4.
- Systems, components and Materials (UPC, 6 ECTS). More than one half of the lectures are delivered professionals from Tecnatom, CIEMAT, ENSA and Nuclenor.
- Fuel Cycle and Environmental Impact (UPC, 5.5 ECTS). About one half of the lectures are delivered professionals from ENUSA and AREVA.
- Regulations and Safety (UPC, 5 ECTS). Most of this course is lectured by external teachers (Regulatory Authority, ENUSA, CIEMAT, Tecnatom) or take place in an industrial facility (Tecnatom's Fulls Scope Simulator)
- Management of Nuclear Power Plants (UPC, 8.5 ECTS). Most of this course is lectured by external teachers (senior retired engineers from ANAV and Westinghouse, and active professionals from ANAV, Endesa, ENRESA, Tecnatom, and Westinghouse) or take place in an industrial facility (Tecnatom's Fulls Scope Simulator, Tecnatom's headquarters in Madrid, one Nuclear Power Plant, ENSA factory in Santander, Endesa headquarters in Madrid, etc.). See figure 4.

- Project course (UPC, 3 ECTS). This course is organised as a transversal PBL activity that students develop in teams and is followed up by specialists from industry together with academic staff.
- Energy and Components (Grenoble INP, 6 ECTS). These courses are delivered by EDF, the main part of it at its premises of the Materials Ageing Institute, where students spend 2 weeks (see figure 4). The courses consist of a detailed synopsis of selected operating experiences concerning PWR primary circuit components which EDF considers to be crucial issues for safety. Specific problems concerning fuel, fuel cladding, internals, pressure vessels, and water chemistry are detailed. This is a unique opportunity for students to learn what are the technological issues that engineers and researchers in materials have to tackle within nuclear industry.
- Nuclear Fuels (Grenoble INP, 6 ECTS). These courses are delivered by CEA – INSTN during 3 weeks stay at CEA Cadarache. This module gives a broad overview of the different key aspects of nuclear fuels which are useful to any engineer intending to work in the nuclear industry.
- Radioprotection 1 & 2 (Paris-Saclay, 5 ECTS in total). These courses are endorsed by CEA, EDF and IRSN
- Labworks on PWR and other systems (Paris-Saclay, 4 ECTS), endorsed by CEA.
- Fuel Cycles (Paris-Saclay, 4 ECTS). This module is endorsed by CEA for the Nuclear Reactor Physics and Engineering major.
- Design and construction of structures and infrastructures (Paris-Saclay, 4 ECTS), endorsed by EDF and BOUYGUES for the Nuclear Plant Design major.
- Systems and equipment (Paris-Saclay, 4 ECTS), endorsed by AREVA for the Nuclear Plant Design major.
- Operation management (Paris-Saclay, 5 ECTS), endorsed by CEA, AREVA and EDF for the Operations major.
- Safety and Production (Paris-Saclay, 4 ECTS), endorsed by EDF for the Operations major.
- Politics, strategy and management of decommissioning (Paris-Saclay, 5 ECTS), endorsed by EDF and CEA (39h, 5 ECTS) for the Decommissioning and Waste Management major.
- Methods of decommissioning (Paris-Saclay, 4 ECTS), endorsed by CEA, SALVAREM and EDF for the Decommissioning and Waste Management major.
- Separation and Recycling (Paris-Saclay, 6 ECTS), endorsed by CEA for the Fuel Cycle major.

Figure 4. Top-left: Visit to Äspö Hard Rock Laboratory. Top-right: In the turbine building of a PWR plant. Bottom-left: at the Materials Ageing Institute (EDF). Bottom-right: at the ENSA factory in Spain.

5. Sharping the saw

EMINE programme is in constant evolution as a result of the continuous interaction of the four local academic institutions with their respective industrial partners (some of them, as well, partners of EMINE). Moreover, the international collaboration among universities helps improving the quality and the adoption of best practices.

EMINE programme pedagogical evolution is also strongly supported by KIC InnoEnergy, which offers opportunities to support teacher's initiative for programme improvement.

In the last editions, new interesting courses have been developed at KTH combining efficiently theoretical and practical skills for the comprehensive competence building, like: Leadership for Safety in Nuclear Power Industry and Geological Storage of the Spent Nuclear Fuel, described above. Students graded those courses above 6.5 on a 0-7 scale. Moreover, the EMINE programme at KTH has developed and started to implement the integration of the entire programme into to E-learning platform in order to improve the pedagogy of the programme and to increase its efficiency.

At UPC, continuous adjustments are done on the contents of the courses. For instance, in the course on Systems, Components and Materials, a couple of relevant actions have been undertaken:

- The module on Systems (Tecnatom) has now a sharper focus on a limited number of systems; nevertheless, all the information given in previous years is made available to the students, so that they can use it in the assignments of the course on Management of Nuclear Power Plants.
- The module on Materials, mainly lectured by CIEMAT, has been made more attainable for students: whereas all the written information is still supplied to the students, lecturers pay more attention to the basic and crucial aspects.

An effort has been recently done at UPC to improve the exercises proposed for the course Management of Nuclear Power Plants. These exercises aimed to be as close as possible to actual engineering activities, e.g. analysing the suitability of the performance of any interface, designing a system, or specifying a component. Over the years these exercises have been adjusted to make them more effective learning tools, focusing the effort of the students on the more crucial aspects and increasing the instances of feedback provided by instructors.

At Grenoble INP a couple of initiatives have been developed as first raw tests. The first one is focused in the "learning by doing" principle and, more particularly, in the idea that "the best way to learn is to teach". A "student conference initiative on world energy issues", with real audience has been proposed and then organized and held with a strong implication of the students. Two different presentations have been made by two groups of 6 students each with the help of 3 scientific experts, in order to allow creativity and spontaneity both in the way of presenting facts and answering questions. Students had to use all their talent to make themselves as clear and convincing as possible. This initiative was a great success. The second initiative explores the innovation potential of the light "tangible games", which are typically games of cards and are the brand new trend of "gamification", in comparison to the "serious games", which impose heavy computing infrastructures.

At Paris-Saclay University the pedagogical committee, gathering the ten academic and industrial partners, improve annually the program during pedagogical meetings taking account for the students' evaluations. For example, the new EDF R&D and training campus in Plateau of Saclay will facilitate reactor simulator sessions for the students from 2017 on. Moreover, a set of conferences has been included in the program, to open perspectives and allow debate between experts and students on Energy themes. Some of them are given by AREVA and EDF senior experts.

EMINE programme has been recently evaluated by the students, who indicated a number of strengths and weaknesses and finally concluded:

- EMINE consolidates unique and specialised courses in the field of Nuclear Engineering – students are very happy about that.
- Providing double-diploma is still a unique thing in European Union. Ability to travel and learn is a dream of every student. While there are some hiccups on organisation side, most of the students are very pleased with this opportunity.
- Cooperation with industry enables EMINE to invite specialists to the lectures. Detailed insight is of high value in this field of science. Usually, these lecturers not only operate state of the art knowledge, but also give to the students an idea about possible work conditions and positions in future career.

6. Conclusions

MSc EMINE helps tomorrow's nuclear engineers take up the challenges the nuclear energy industry faces in terms of safety, social acceptability and waste management. By offering outstanding technical training and addressing the economic, social and political aspects of nuclear energy, the programme broadens the scope of traditional nuclear education.

KIC InnoEnergy offers scholarships to the best EMINE applicants and covers as well the participation costs at the hosting universities. This fact, along with the quality and focus of the programme and the industrial implication, helps EMINE attract good students.

The EIT funding and the industrial involvement allows a number of activities that otherwise would be difficult to carry out, such as the assistance of external industrial experts or field activities. The latter include several visits to factories, plants or even to an underground laboratory for Geological Storage of Spent Nuclear Fuel. The participation of external specialists in the lectures not only provides an insight on the state of the art, but also gives students an idea about possible work conditions and positions in their future career.

EMINE students receive the high-level technical education required to master the engineering complexities of nuclear power generation, as well as business training related to innovation issues and energy management. The programme helps students integrate the technical aspects of the nuclear industry with key political, economic and social issues.

EMINE offers students the possibility of carrying out an international MSc Programme of quality with large industrial involvement and allowing them to travel within Europe. The design of EMINE is attractive, combining science and technology with management and innovation in the energy field and leadership skills in nuclear safety, bringing to the classroom real industrial problems to be solved by students, and deploying a series of engaging pedagogical methods like PBL or e-learning strategies.

On finishing this MSc Programme, students enjoy of good job or PhD opportunities in the nuclear industry worldwide.

For more information

http://www.kic-innoenergy.com/education/master-school/msc-emine-european-master-in-nuclear-energy/

http://eit.europa.eu/