Recent experiment of nuclear engineering education in Italy

RECENT EXPERIMENTS IN NUCLEAR ENGINEERING EDUCATION IN ITALY

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ABSTRACT

Education has a crucial role for the future of nuclear energy, even more after the Fukushima accident. It is necessary to guarantee the natural turn-over of human resources employed in the field and to prepare qualified engineers and researchers to study and design the future generation of nuclear systems, with a stress on enhanced safety, more efficient fuel cycle, radioactive waste transmutation, security. The Italian situation is peculiar owing to the nuclear energy phase-out, that was decided, after a referendum in 1987, following the Chernobyl accident, and more recently, after another referendum in June 2011, just after the Fukushima- Daiichi accident. After a short history of the Nuclear Engineering education in Italy since 1955 the paper presents the current Nuclear Engineering courses in Italy, and in particular the Master level Nuclear Engineering Course that has been organised this year in collaboration between the Politecnico di Milano and Politecnico di Torino.

1. Introduction

The present panorama of nuclear energy in the world is quite varied: in “old industrial Countries”, a recent wave of renaissance was somehow slowed down by the Fukushima Daiichi accident [1]; there are problems with public acceptance due to poor awareness of risks and benefits, lack of accurate information, no real incentive. There is also some uncertainty in taking decisions at the political level owing to the lack of belief in policy makers and the fear of loosing consensus; the issue of the increasing cost to build the plant is also important, although the costs depends strongly on the Countries [2]. Instead in “new industrial Countries” the access to nuclear energy is regarded as an opportunity and is being largely exploited: new constructions are carried on. In such contest education is fundamental for the future of nuclear energy, even more after the Fukushima accident, as it is necessary for the natural turn-over of human resources and to prepare qualified engineers and researchers to study and design the future generation of nuclear systems, which have to be characterized by enhanced safety and security, sustainability and more efficient fuel cycle, radioactive waste transmutation. The need to preserve, enhance or strengthen nuclear knowledge, skill and aptitude (ECVET) is recognized by the main international Institutions, like IAEA: there are indicators, e.g. declining university enrolment and high retirement expectations, that future expertise is at risk. The Italian situation is peculiar but it must be mentioned that when the Italian government decided to abandon the nuclear energy production, at the end of eighties, gave in some way the universities and research Centres, like ENEA, the task to maintain alive the expertise, the research and the education in this area, also to address the issues of nuclear fusion, of decommissioning of the nuclear facilities and of radioactive waste management. After a quick history of the Nuclear Engineering education in Italy since 1955, the paper presents the current Nuclear engineering courses in Italy and, in particular, the Master level Nuclear Engineering Course that has been organised this year in collaboration between the Politecnico di Milano and Politecnico di Torino is presented.

2. Nuclear engineering education

It is a widely shared opinion that nuclear education is playing a fundamental role to enhance the current and future nuclear renaissance. Unfortunately, in the last two decades in almost all Countries, universities have experienced quite severe reductions in the nuclear engineering programs at all levels, due to the decline of the number of students and to the generalized cut of funding. In Italy the problem has become really dramatic, because the Country has pulled out of the nuclear generation of electricity and resources were reduced for the universities where nuclear programs were active. Education of qualified nuclear specialists has now become a big concern of international organizations and, more recently, of nuclear industry and research laboratories. Similar concern for nuclear education has been also stated by the European Nuclear Society in very recent times [3]. Particularly significant is a statement by OECD Steering Committee [4] for Nuclear Energy / European Nuclear Society: “the availability of qualified human resources is a prerequisite to the safe operation of existing nuclear power plants as well as to the recourse to nuclear energy in general: a regular monitoring of the availability and requirements of qualified human resources is necessary to match the existing and future needs; governments, academia, industry and research organizations should collaborate, both nationally and internationally, to enhance nuclear education and availability of nuclear expertise, including financial support to universities and scholarships to students”. Hence the OECD Steering Committee for Nuclear Energy conveyed to the member governments a warning to suggest a regular monitoring of the availability and requirements of qualified human resources to match the existing and future needs. It is particularly stressed that “governments, academia, industry and research organizations should collaborate, both nationally and internationally, to enhance nuclear education and availability of nuclear expertise, including financial support to universities and scholarships to students”. Furthermore, “governments, whether or not they choose to utilize nuclear power, should also encourage large, high-profile, international R&D programs which attract students and young professionals to become the nuclear experts required for the future”. In September 2002, the (IAEA) General Conference requested the Director General to note the high level of interest of Member States in the range of issues associated with preserving and enhancing nuclear knowledge in the process of preparing the Agency's program. Worry for nuclear education is shared by several international institutions (OECD, ANS, NEA, IAEA, EU…), industries, utilities and research labs (CEA, AREVA, DOE, NRC…). After the Fukushima- Daiichi accident the risk to have insufficient human resources in the next years is even more realistic than in the past, when a growing interest for nuclear educational programs was experimented in many Countries. It must be acknowledged that to produce an engineer (Master graduate) for industry and utilities more than 5 years are needed; to produce a PhD graduate more than 8 years are needed; to prepare a good university instructor more than 10 years are needed and good motivations and perspectives must be offered to the best youth. The profile of the Nuclear engineer is implied by the courses he is supposed to attend and pass at the MSc level and by the related learning outcomes. In the past, there was some need to clarify that Nuclear engineers cannot be identified just with physicists or experts in neutronics or in any other single matter related to nuclear, but Nuclear engineers should be identified with engineers having that broad spectrum of competences needed to design, construct and operate safe nuclear power plants.

3. Nuclear engineering education in Italy

3.1 Short history

Italy started to build nuclear power plants early: three first generation nuclear power plants (PWR, BWR, Magnox) started operation before middle sixties. The 860 MW_e Caorso BWR NPP started running in 1981: a 2000 MW_e NPP with two BWRs was under construction in Montalto di Castro in the eighties; a 2000 MW_e NPP with two PWRs was planned in Piedmont and several research reactors were built in the same period. As regards the education, since 1955 several initiatives (in the form of post degree Courses for mechanical, electrical, chemical engineers) were undertaken

in Italy in the field of the nuclear education: from 1960 to 1966 six Universities set up Nuclear engineering Courses that delivered a five year N.E. degree: “Polytechnic Schools” of Milano and Torino, universities of Bologna, Pisa, Palermo and Roma. The number of Nuclear engineering enrolled students increased up steadily until the first nineties, and after then, with some oscillations, decreased to the values of less than ten per year in each of the mentioned universities. The number of the Nuclear engineering graduated students per year increased in Italy up to about 250 in the first eighties and decreased later to less than 100 (Fig.1).

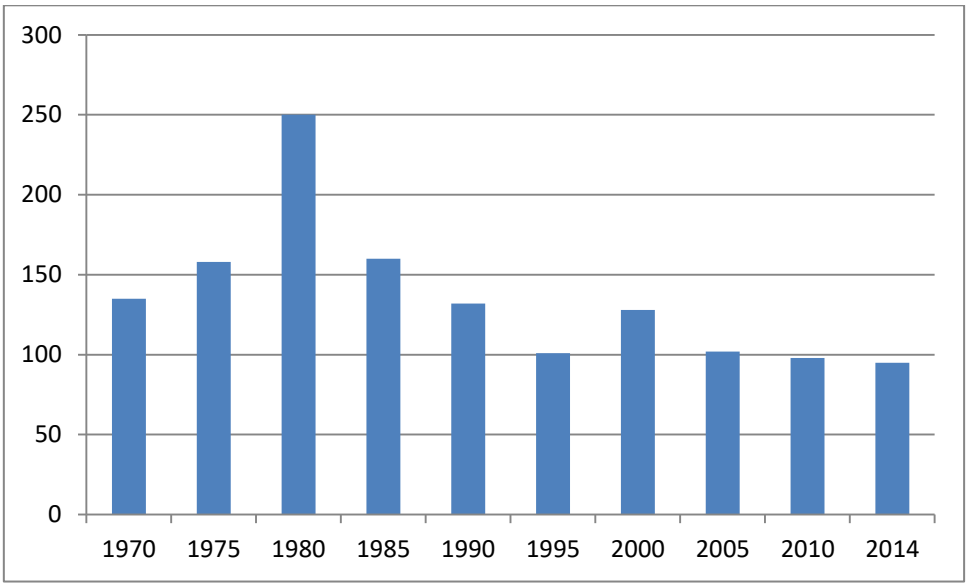

Fig. 1 History of Nuclear engineering graduated students in Italy

After the first Referendum in 1987 either the Italian universities and the research centers or the industry and the national utility began to struggle for maintaining the nuclear knowledge, in order to be able to manage the radiation protection and decommissioning issues and to be competitive in the European nuclear market. The Board of each N.E. Course decided:

- to stress the methodology aspects and the contents that could be easily extended to whatever engineering application, like the thermal-mechanics, thermal- hydraulics, reliability and risk analysis
- to strength the topics concerning the innovative reactors and the nuclear fusion engineering, as well as the issues related to the radiation protection
- to intensify strongly the contacts with universities and Research Centres abroad.

Some years later, at beginning of the XXI century, a significant effort has been carried out in Europe to homogenize the various academic systems for all disciplines: a curriculum constituted by a three-year bachelor program followed by a two-year master and a three-year doctorate (3+2+3 Bologna system) has been generally accepted and then introduced, together with the European Credit Transfer System (ECTS), which in Italy means 10 hours of lecture (and about 25 hours of student global commitment) per ECTS. It is worth mentioning that the nuclear education has profited from this framework, enhancing mobility of students for courses, stages and Master thesis. In 2012 the Italian Government has issued a document on the “National Energy strategic plan: for a more competitive and sustainable energy”, reporting that “as regards the Nuclear energy the prevision for the next 10 years in the world is an increase in Asian Countries (in particular China, Korea, India, Russia), while in the West and particularly in Europe no significant increase of the Nuclear Power Plants will occur because of the high construction costs and the safety issues of this technology. In USA and Europe (and particularly in Italy) the emphasis will be put on the NPPs decommissioning and wastes treatment and storage. Further research work is needed to

improve the NPPs safety and security. Concerning the Italian situation in the long term, it is important to increase the international collaborations on the nuclear safety, on the IV generation reactors and on the nuclear fusion".

3.2 Present situation

The Nuclear engineering courses in Italy have always tried to give the students rather good bases and a system oriented approach to problems that can be used successfully in different engineering areas; so the Italian nuclear engineers are rather able to deal with complex problems and often are appreciated abroad, but, as pointed out above, in Europe, but especially in Italy, universities have gone through several years of difficult time as far as financial and human resources are concerned. Retirement of several professors are practically empting many nuclear research teams in some Italian universities, making hard to maintain nuclear engineering programs. Even in such a difficult situation, the Italian Nuclear engineering education system has done its best to maintain the excellence of programs and to enter international cooperation frameworks, in order to attract good and motivated students. The collaboration among universities offering nuclear programs has been enhanced both at the Italian and at the international level. The institution of an Italian consortium of universities (CIRTEN [5]) has allowed them to perform well both scientific research and education. At the European level a large scale consortium of universities (ENEN [6]), that includes CIRTEN, has been set up for establishing common requirements for a mutual recognition of degrees. The recognition of education requisites will certainly favor the mobility of students within European universities (often by means of Erasmus programme) and the recognition of degrees can enhance mobility of graduates for PhD and for job placements in industry and research laboratories. Besides enhanced collaborations with many European universities, several agreement have been established with many universities in Asia and America. Within this framework, several student and young researcher exchanges have taken place among the involved institutions and double degree programs have also been established with many universities. The job placements of Nuclear engineering graduates has seldom been a problem. Due to the good background in basic scientific disciplines (mainly mathematics, physics and computational methods) and to the interdisciplinary characteristics (thermodynamics and heat transfer, mechanics, material science, safety) of the programs they can easily find satisfactory opportunities in several technical fields (mechanical, aerospace, chemical, nuclear) around the world, in industry, labs and academia. The Nuclear engineering education in Italy is currently offered at Master and PhD levels in Milano, Torino, Pisa and Palermo universities, and to a lesser extent also in Roma and Bologna Universities. The Master degree names are different: Nuclear engineering in Milano and Pisa, Energy and Nuclear engineering in Torino and Palermo, Energy engineering in Roma and Bologna, but the content of the basic nuclear modules is similar. There are several topics that are common to most universities: Reactor engineering and technology, Reactor physics, Nuclear power plant thermal hydraulics, Safety and reliability of nuclear facilities, Reactor engineering materials, Radiology and radiation protection, Nuclear fuel cycle and applied radiochemistry, NPP decommissioning and waste management. Other topics like Nuclear Fusion, Nuclear medicine applications, Nuclear instrumentation and measurements, Plasma industrial applications are addressed in some Universities. As an example at Politecnico di Torino the enrolled students in Energy and Nuclear engineering can choose the Technology and Nuclear applications branch with 72 nuclear credits plus 16 credit nuclear subject thesis. In Table 1 the nuclear engineering ECTS in each university is presented. There are also some Nuclear engineering courses at bachelor level in some universities. E-learning methods, as well as the use of social networks to communicate with the students, are widely adopted: an example is the Facebook page of the Pisa university:
http://www.facebook.com/pages/Studiare-Ingegneria-Nucleare-a-Pisa-Nuclear-Engineering-Studies-in-Pisa/391575160888508#!/pages/Studiare-Ingegneria-Nucleare-a-Pisa-Nuclear-Engineering-Studies-in-Pisa/391575160888508.

Program name	University	Nuclear engineering ECTS
Nuclear engineering	Politecnico di Milano	85
Nuclear engineering	Università di Pisa	90
Energy and Nuclear engineering	Politecnico di Torino	72
Energy and Nuclear engineering	Università di Palermo	66
Energy engineering	Università di Roma	45
Energy engineering	Università di Bologna	36

Tab 1: Master degree Nuclear engineering credits in Italian universities

In the last years the interest of young people for energy problems has increased dramatically. As an example Fig.2 shows the evolution of the enrolled students at Politecnico di Torino in ten years. In the last years about 20% of these students has chosen the Nuclear engineering branch, but for all students some Nuclear engineering courses are mandatory.

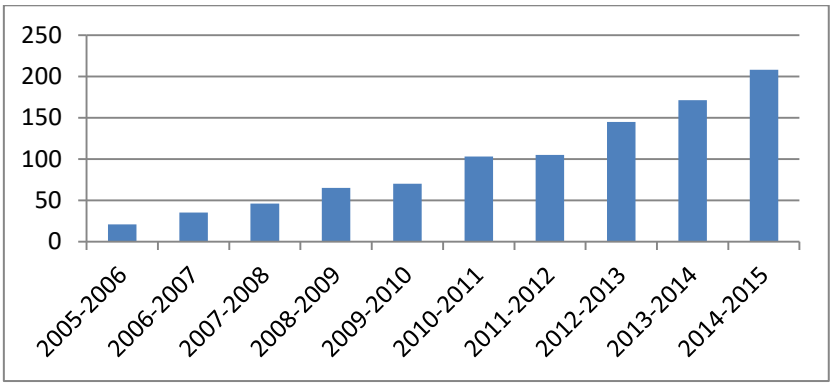

Fig. 2. Students enrollment number evolution in Energy and Nuclear engineering Master at Politecnico di Torino

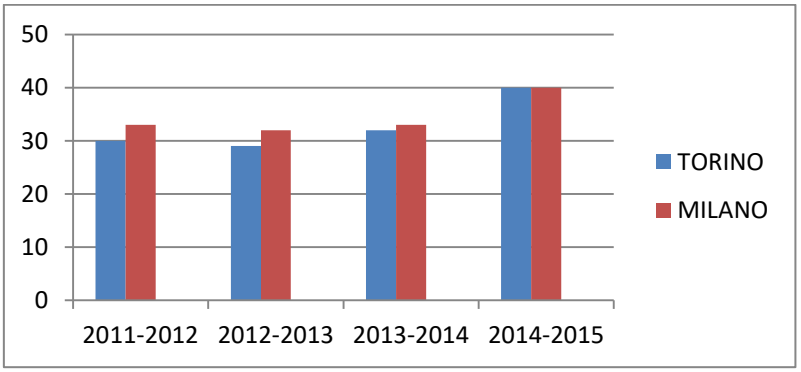

Fig. 3. Students enrollment number in Nuclear engineering Master at Politecnico di Torino and Politecnico di Milano in the last four years

The number of Master students in Nuclear engineering in Italian universities has been about constant, also after the Fukushima Daiichi accident. For instance Fig.3 shows the enrolled students evolution in the last five years at Milano and Torino Polytechnic Schools. The number of Master graduates in Nuclear engineering in Italian universities amounts in the last years to about 100 per year. Concerning the teachers, at present 64 Professors and Assistant Professors in the six Italian universities educate the students in the Nuclear engineering field (Fig. 4), carrying out researches on nuclear engineering related issues; this number is decreased in the last years due to the professors retirements and the economic difficulties (Fig. 5).

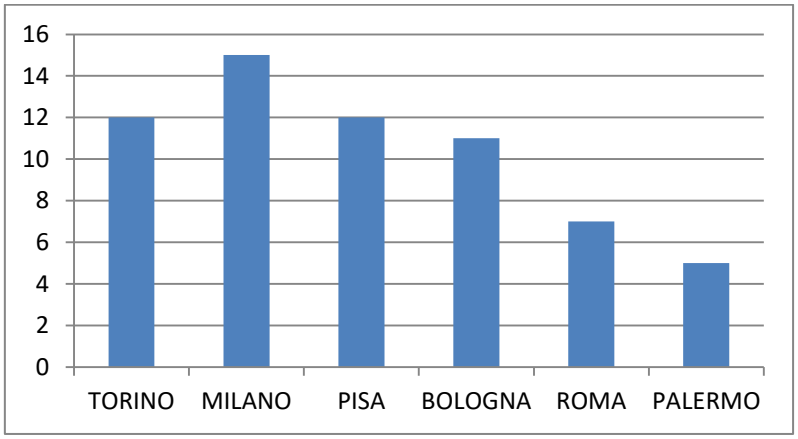

Fig. 4. Current Nuclear engineering teachers in each university

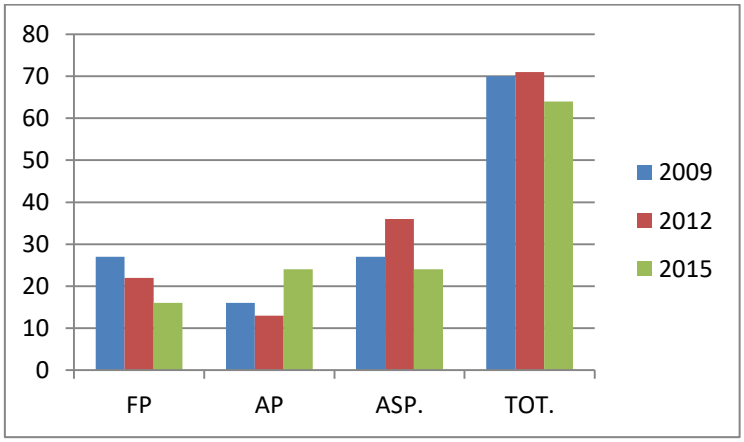

Fig.5. Nuclear engineering teachers evolution in Italy (FP full prof., AP associate prof., ASP. assistant prof.)

4. International collaborations

Concerning the international collaborations in the education field, some actions have been taken by the Italian universities: by activating, often as CIRTEN, several international collaborations and undertakings like ENEN (European Nuclear Engineering Network); by participating, as CIRTEN, to several Nuclear engineering education European projects (FP6 and FP7): ENEN I, II, III, Neptuno, ENEN-RU, ENEN-China, TRASNUSAFE, GENTLE, NUSHARE, ANNETTE. There is an enhanced mobility of Italian students in Europe, stimulated by the adoption of the Bologna system and by the

ENEN initiatives like the European Master of Science in Nuclear Engineering (EMSNE). EMSNE has been implemented since 2006, on the basis of common reference curricula and at least 20 nuclear ECTS gained abroad: it promotes and facilitates mobility of students and teachers and allows the definition and assessment of ENEN international exchange courses. “EMSNE Certificate” is recognised among ENEN Members (more than 45 universities) with the objectives to educate students towards analytic, resourceful and inventive nuclear engineers by combining the joint state-of-the-art know-how of the participating universities; to train these students by making full use of the unique nuclear research and industrial facilities throughout Europe; to develop a common safety culture throughout Europe; to develop an international network of nuclear engineers and scientists by participation of students of different nationalities, by contact and collaboration with local students, and by education in several countries with different educational views, different nuclear reactor concept and technologies, and different nuclear policies. The possibility to adhere to similar curricula in Europe would facilitate student exchanges with a great benefit for students, that learn to be “international”. It further develops the collaboration in nuclear education and training of students, researchers and professionals all over Europe, ensures the quality of nuclear education and training, increases the attractiveness for engagement in the nuclear fields for students, researchers and professionals, promotes life-long learning and career development at post-graduate or equivalent level. In this way it is possible to synchronise teaching in different universities with similar in basic “core” nuclear matters and complementary advanced topics. More than 50 Italian students have received the EMSNE certificate in 10 years.

5. The doctoral programs

A qualified PhD programs is certainly one of the key-points in nuclear education at higher level, which can only be guarantied by highly-qualified research projects that require the contribution of PhD candidates. In each previously mentioned Italian university there are about 3 Ph.D. students per year who carry out nuclear engineering thesis (increasingly abroad). PhD Italian students have spent study periods at: CERN, Los Alamos, Argonne, NAKA, CEA-Cadarache, CEA-Saclay, Garching, Virginia Tech., UC Berkeley, Lisboa, Aalborg, Trondheim, PSI Zurich, Karlsruhe FZK, Areva Erlangen, Areva Paris. Some data related to the past ten years are certainly interesting and deserve some comments. For instance since the beginning of the Bologna system at Politecnico di Torino about 120 students have graduated in Nuclear engineering and it is significant that after graduation fifteen out of them have undertaken a PhD program abroad in Europe and over ten in Italy. This high fraction clearly shows the scientific interest of graduates in the field and their motivation to undertake a scientific career, often to be performed abroad.

6. Recent Politecnico di Milano and Politecnico di Torino initiative

Politecnico di Milano and Politecnico di Torino have 50 years long tradition and well recognized quality in nuclear engineering education and research. The Joint Master of Science Program in Nuclear Engineering, taking also in account that the two towns are rather near each other (about 1 hour of train), is a new initiative, launched in the academic year 2015-2016, and a unique opportunity to take advantage of the complementary know-how present in the two Universities, as well as to get access to state-of-the-art laboratories, including the research reactor TRIGA at LENA-Pavia and several other experimental and computational labs and facilities (nuclear electronics, nuclear instrumentations and measurements, radiation protection, radiochemistry, thermal-hydraulics). Moreover the foreign students can become part of a lively and stimulating international academic community, and can enjoy the Italian cultural environment. The program consists in two-year Master Science program focused on the various aspects of Nuclear engineering (fission reactor physics and engineering, fusion reactor physics and engineering, laboratory of nuclear reactor kinetics, radiation protection and radiochemistry, biomedical and industrial applications of radiation, safety of nuclear installations, thermal hydraulics, CFD etc.). The students will take courses in both universities (the first year at Politecnico di Torino and the

second year at Politecnico di Milano, or vice versa), and will earn a Master's Degree in Nuclear engineering in the university where they have chosen to be enrolled and where they will carry out the master thesis. As an example, for students enrolled by Politecnico di Torino, the Master programme (including the Nuclear engineering courses only) is shown in Table 2:

Courses held in Torino (I year)
Mandatory courses(58 ECTS)
Monte Carlo methods, safety and risk analysis (10 ECTS)
Nuclear reactor physics and transport theory (10 ECTS)
Nuclear fission plants (8 ECTS)
Radiation Protection (6 ECTS)
Biomedical and industrial applications of radiation (6 ECTS)
Computational methods for thermo-fluiddynamics (6 ECTS)
Nuclear fusion reactor physics(6 ECTS)
Nuclear fusion reactor engineering (6 ECTS)
Master thesis to be carried out in Torino at the end of II year (16 ECTS)

Courses held in Milano (II year)
Mandatory courses (25 ECTS)
Nuclear design and technology (10 ECTS)
Dynamics and control of nuclear plants (10 ECTS)
Experimental nuclear reactor kinetics (TRIGA reactor- Pavia University) (5 ECTS)
Optional courses (15 ECTS) between
Integrated deterministic and probabilistic safety analysis of nuclear power plants (5 ECTS)
Physics of nuclear materials (5 ECTS)
Plasma physics (5 ECTS)
Applied radiochemistry (5 ECTS)
Computational methods for reliability, availability and maintenance (5 ECTS)
Industrial and nuclear electronics (10 ECTS)
Radiation detection and measurement (10 ECTS)
Safety assessment of radioactive waste repositories (5 ECTS)

Table 2: Joint Master of Science Program in Nuclear Engineering for students enrolled by Politecnico di Torino

As regards the Experimental nuclear reactor kinetics course by using the TRIGA reactor, there is an agreement between the two Polytechnic Schools and the Laboratory of Applied Nuclear Energy ("LENA") of the university of Pavia which operates a 250 kW - TRIGA Mark II Research Nuclear Reactor [7]. In particular LENA offers education and training courses for students in the field of nuclear reactor physics and kinetics on the following subjects:

1. Determination of the value of the effective multiplication factor (Keff) in subcritical reactor condition;
2. Critical mass evaluation by means of the inverse multiplication factor method;
3. Approximate calibration of reactor control rods;
4. Fine calibration of reactor control rods by the method of reactor period;
5. Measurement of fuel Temperature Coefficient (prompt and stationary);
6. Measurement of the moderator void coefficient;
7. Analysis of delayed neutrons kinetics during reactor power transients and shut-down;
8. Measurement of reactor neutron fluxes.

7. Conclusions

The analysis of the Italian situation in the field of Nuclear engineering education points out to some severe problems, arising mainly from the two referenda against nuclear energy development. The consequence has been the shrinking of the specialized faculty and the difficulties connected with the reduction of public resources. To meet the needs in human resources of industry and research in the near future (especially for topics like nuclear power plant decommissioning and waste management, nuclear safety and security, nuclear fusion), industry

and universities should closely collaborate and serious political decisions oriented to maintain competences and educational excellence in the field should be taken. The role of international projects and collaborations should be always more important and to preserve the Nuclear engineering and technology culture the Italian universities, like other Countries universities, should make their best efforts to attract the best students. The task is difficult, owing to the international and national contest, but the nuclear experts, involved in the Italian academic institutions, are trying to maintain as high as possible the knowledge and the cultural level of the human resources in this field, also to address important issues for Italy like decommissioning and waste management, generation IV reactors, nuclear fusion plants. The well-established CIRTEN (Consorzio Interuniversitario per la Ricerca Tecnologica Nucleare) consortium, the international collaborations, like the European Nuclear Education Network (ENEN) and the recent Politecnico di Torino and Politecnico di Milano Joint Master of Science Program in Nuclear engineering with the opportunity to take advantage of the complementary know-how present in the two Universities (including the Experimental nuclear reactor kinetics course at TRIGA reactor of the Pavia University), are worthy initiatives to improve the education and skill of the Italian nuclear engineering students.

8. References

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