**Nuclear Education & Training activity experience at the University of Pavia**

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**Abstract** At the University of Pavia, at the Laboratory for Applied Nuclear Energy (LENA) is installed a 250 kW TRIGA Mark II Type Research Reactor together with a radiochemistry laboratory dedicated to the manipulation, analysis and radiochemistry separations. As an University institution, one of the main purposes is to prepare new generations of students and graduates for their careers. The Laboratory, as a facility at the disposal of different University departments, provides practical exercises as part of university classes in particular for Physics, Chemistry and, within agreements with other Universities, also in nuclear engineering. The University of Pavia, in consideration of its facilities and expertise, hosts international courses and hands-on training to foreign Regulatory Body personnel, health physics staff and radiation protection advisors. The assets and key points of practical courses are discussed together with a list of the achievable expected outcomes.

1. **Introduction**

Nowadays, the nuclear field (industry, government authorities, R&D organizations and educational institutions) has a constant need for specialized, highly trained and motivated workforce for its sustainability. High standards of performance are expected for the workforce employed in this field and their specialization is a key issue in order to grant and maintain efficiency and high safety levels. The University of Pavia offers training, laboratories and experiences in different academic courses; within this framework, the Laboratory of Applied Nuclear Energy (LENA) [1], actively contributes to E&T (Education and Training) activities thanks to a consolidated expertise gained in almost 50 years of reactor operation. LENA can offer a wide range of education and training programs covering most of the topics related to the nuclear field: from safety culture and radioprotection to research reactor maintenance and quality assurance. Training courses are held by qualified professionals working at LENA or by professors from the University of Pavia as well as part of the educational path from other universities or institutions contributing to courses for Nuclear Engineering, Physics Master Degrees and for post-graduated International Masters in the subjects of Reactor Physics, Radiochemistry, Radiation Protection and Nuclear Instrumentation.

1. **Courses description**

The following paragraphs aim to provide some examples of the most relevant training and educational activities among those held at LENA. This list shows as a flexible facility, with a low power research reactor, can be usefully applied to the academic world and how could be a strong support to training activities for employees in nuclear field.

1. **Radiochemistry**

Course of Radiochemistry (University of Pavia) where teaching exercises are expected in the radiochemistry laboratory providing instruction on all aspects of radiometric measurements as well as laboratory safety. This unique hands-on training will provides the basis for highly effective radiometric operations and establishes principles for effective and proper radiometric laboratory operations.

1. **Practical exercises on reactor kinetic**

Practical exercises on reactor kinetic within the course on Nuclear Plants, Nuclear Engineering are routinely operated in cooperation with the Polytechnic of Milan. The practical exercises are carried out at LENA where, assisted by the reactor staff, students can experience typical nuclear tests and measurements, actively participating in data collection, data qualification and analysis. In this case, the availability of an operating RR represents a great added value to the typical classroom activities. In this sense, the synergy developed between theory and practice has to be highlighted as noticeable asset. Nowadays, thanks to the availability of new technologies, in particular the development of virtual RR, it is given to distant learners the possibility to assist, through the web, to actual reactor operations. Currently, as an example, it is underway the organization, with preliminary agreement made with the University of Bologna, for the exploitation of this new capability for future on-line courses. The main practical exercises, among others [2], include :

1. **Void coefficient**

The reactor void coefficient [3] measurements allow students the estimation of how the reactivity is affected by typical situations such as steam and bubbles in a moderator and coolant of a nuclear reactor. In particular, this experiment is carried out with a defined volume of water inserted in the Central Thimble, which is equivalent to a reactivity variation; then, coming back to stable situation, it is possible the evaluation of the void coefficient using the worth of control rod calibration.

1. **Control rods worth calibration**

Rods calibration curves are determined by the method of reactor period T measurements. Students can obtain a practical demonstration of the reactor behaviour. To carry out this experiment students use commercial chronometers to measure the time DT during which the reactor increases the power of a factor 1.5. Using the relation between reactor period and DT time, through the plot of in-hour equation(for TRIGA Mark II reactor), students are able to relate the reactor period to the reactivity and finally obtain the rod curves calibration.

1. **Reactor power calibration (with calorimetric method)**

Students perform power calibration [2] using the method of calculation of temperature increase rate of the system core plus tank, in adiabatic condition. This is one of the method proposed by General Atomic technical documentation and present also in the procedures available on the reactor plant. The reactor power is increased to 15 kW, a power level where temperature effects begin to affect reactor power, and they collect data of water temperature every 15 minutes for a period of about 2 hours. Plotting the water temperature T (C°) versus time (hours) and calculating the reactor mean power and considering the heat capacity of the system (water + core) it is possible to compare the result of calculated power with the reactor power indicated by the consolle instrumentation.

1. **Reactor effective multiplication factor**

Reactor kinetic is normally studied in nuclear reactor engineering textbook [4]. A practical course running the reactor at different power levels allows students to understand the reactor kinetic and its dependence on different factors such as such as core poisoning, thermal effects (prompt and delayed), control rod effects, etc.

1. **Core excess and shut down margin**

Determination of excess of reactivityand shut-down marginof a reactor core are two of the most strict requirements for safety reactor operation. Starting after the rods calibration the Operational Limits and Conditions (OLC) are verified. With this experience is it possible to understand concepts such as OLC and how the reactor documentation is related to safety aspects of reactor operation.

1. **Course of Cellular Radiobiology (University of Pavia)**

Introduction to the effects of neutron fields on cells and tissues. Overview and description of main facilities available at TRIGA of LENA with interest in biological studies.

1. **Radiobiology**

Lessons on neutron physics for the Physics Department of the University of Pavia (Radiobiology and EURATOM course). The course provides a first introduction to all the aspects of neutron interaction with matter, focussing on main interaction processes related to secondary charged particle spectra generated in tissue and RBE of neutron.

1. **Master in Hadrontherapy**

Lessons for the Master in Hadrontherapy (organized by CNAO Foundation - National Center of Oncological Hadrontherapy) on various topics related to neutron physics and their application. In particular main aspects of operative radioprotection procedures in a research reactor plant have been presented together with training activities. Environmental monitoring and radioactive waste management have been also introduced and described with particular attention to the regulations in force.

1. **Radioactivity Course - Physics**

The purpose of this course is the understanding of the radioactive risks and their possible technological applications. Subjects are the law of radioactive decay, radioactive Families, Natural Radioactivity, Radiation-Matter Interaction, biological effects of radiation, radon, nuclear accidents, radiocarbon dating, measures of concentration by activation method, gamma decay, alpha decay, other decays and decay measurement of the neutrino mass. Practical experiences follow the program; in particular students use different detectors in a real situation in a research reactor along the daily activity. Experiences applied to the Activation Analysis are given.

* 1. **Simulation** **in** **bio-sanitary physics and laboratory of physics of ionizing radiation**

The program of these courses focuses on the reproduction, through Monte Carlo simulation toolkits, of the transport of ionizing radiation through matter for medical application, shielding studies, and reactor flux calculation. Comparison between simulation results and available experimental data offers a validation of the models adopted in the simulations.

1. **International E&T activities**
2. **Boron Neutron Capture Therapy (BNCT) related activities**

The research group dedicated to Boron Neutron Capture Therapy (BNCT) actively works at LENA since many years. In addition to the experimental and simulation activities, there is an intense exchange of students, post-docs and researchers from different countries that perform their work in this discipline. The most important collaboration is with Comisión Nacional de Energía Atómica (CNEA), Argentina: researchers and students have spent visiting periods in Pavia comprising experimental measurements (boron concentration measurements and dosimetry), calculations (treatment planning and computational dosimetry) and teaching activities (lessons at University courses and seminars). One Ph.D. student from CNEA is performing his research activity in Argentina and in Italy, dedicating to boron concentration measurements in bone. A Ph.D. student from Brasil (University of Campinas) is currently guest at University of Pavia to perform experimental measurements at the BNCT facility of the TRIGA reactor. D. Nigg from DOE, USA, spent two visiting periods at LENA, performing experimental neutron spectrometry and offering to students two cycles of lessons about multifoil neutron activation analysis method. A number of BNCT experts from Finland, USA, Taiwan have been hosted to give lectures on clinical and preclinical experiences at nuclear reactors.

1. **Master on Nuclear and Ionizing Radiation Technologies**

The long-standing cooperation between the University of Pavia and the International Master on Nuclear and Ionizing Radiation Technologies – NIRT, also held in Pavia by IUSS (Istituto Universitario di Studi Superiori), represents a relevant example of fruitful cooperation, where the University of Pavia contributes with several lecturers (almost 30%) as well as provider of practical training stages. The NIRT master, aims to form trainees willing to operate in the field of nuclear technologies and non-power nuclear activities. The annual master course allocates four months of hands-on training stage in institutions/industries. In this context, LENA has been cooperating since several years, providing lectures and practical training in various fields related with the operation of a RR facility. The most recent trainings carried out were focussed on NAA (Neutron Activation Analysis), advanced maintenance techniques, regulatory aspects (e.g. Safety reports, licensing), Quality assurance where the trainees, under the supervision of the plant staff, have had the opportunity to transfer their classroom knowledge in real-life applications. This particular approach demonstrated to be able to boosts productivity because the trainees are working while learning and also because they constantly have a trainer available to ask questions, making easier to understand what is being taught since real-world applications can be seen first-hand rather than just presented in a lecture. These stages are dedicated to understand the radiation effects on matter. Students get familiar with the radioprotection devices. The check of the instrumentation is done with gamma, alpha and beta sources measured at different distances. Experiences on semiconductor detector are used as tools to discover Compton, pair production and photopeak effects in matter. After that, an example of Neutron Activation Analysis (NAA) is shown. The method is described and explained together with some practical analysis performed by directly the students.

1. **Training experience within international networks**

A significant share of the education and training program activities [6] is devoted to fellowship within international cooperation frameworks such as the IAEA Technical Cooperation programs or specific agreements. One of the main assets of these kind of activities is training on specific aspects related to the operation and management of RRs, completing the theoretical background of trainees which will be operating in the nuclear field. The possibility to apply theoretical knowledge on a real work environment, assisted by qualified and experienced staff, is in fact a distinctive feature of these activities, where the strong component of hands-on exercises plays a key role in perfecting the capabilities of the trainees. Fellowships have in general duration of a few months, in order to let the trainees to familiarise with the plant activities. During the last few years LENA has been hosting trainees from different operating organizations or regulatory bodies; the main training requests were on radiation protection aspects, NAA techniques and operators training, but it is interesting to point out how, in the recent years, a growing request related to quality management systems, maintenance and RR safety is taking over.

1. **Industry and consulting E&T activities**
2. **On the Job training on operation and safety aspects of research reactor**

The following typical training week was organized by ITER Consult inside a EU framework:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Monday**  | **Tuesday**  | **Wednesday**  | **Thursday**  | **Friday**  |
| WelcomeOrganizational aspectsTraining Course objective andprogram EU framework for NS and RPGeneral presentation ofoperational/safety aspects ofLENA (history, reactor purpose,characteristics, layout, currentexperimentalfacilities/capabilitiesGeneral presentation of safetyaspects of the RR, national requ’sand international requ’s (IAEACode of Conduct) | Demonstration of reactor startupreactor operation and shutdownGet familiar with safetyManagement at the RRand provisions forRadiation protection,waste management anddaily environmentalmonitoringGet familiar with the research(experimental) activityperformed by LENA reactor | Get familiar with theTechnicalSpecifications and thefactors to be takeninto account whileelaborating the(OLCs)Demonstration oflinks between OLC’sand the safe operation of the RR | Get familiar with the emergencypreparedness at LENAGet familiar with theenvironmentalradiological monitoringat LENA in emergencyscenario | LENA interfaces withItalian nuclearregulatory Authorityfor licensing andinspection activityLENA Safety Analysis Reportand its periodic updatingObjective and scope of thePeriodic Safety Review (PSR) |
| **Lunch** | **Lunch** | **Lunch** | **Lunch** | **Lunch** |
| Walk-down to get direct view of reactor operational and safety systems (control room, reactor hall, reactor platform, basement, hot cell laboratories, waste treatments system, accessible systems structures and components, etc.) | Practical application of an experiment Reactor Power Calibration including * Safety assessment of the experiment
* run the experiment
* perform measurements
* discus accident scenarios

discuss the results | Periodic test of the RR as required by Tech Spec’s:* Test objective
* Link with the safety analysis
* Test planning
* Test implementation
* Test reporting

Non-conformity | Practical application of anexperiment of VoidCoefficient, Core Excess, Shut-Down Margin, Rod WorthCalibration including* Safety assessment of the experiment
* run the experiment
* perform measurements
* discus accident scenarios
* discuss the results
 | Summary of the OJT (ITER,LENA)Final discussionConclusionMinutes of the OJT training |

1. **Nuclear culture**

Due to the needing of increase the nuclear culture within private companies, a compendium of base courses related to safety, reactor kinetics, nuclear measures and radioprotection are provided choosing within the listed expertise.

1. **General activities**

In the field of education it’s also included the Qualified Expert preparation of candidates to the “Radiation Protection Advisor" exam at the Ministry of Labor.

Besides the above described activities addressed to university students and professionals, since many years, LENA has been promoting the information about nuclear field providing guided visits to the reactor facility. This activity is particularly addressed to students from high schools, in order to promote nuclear energy and give adequate information to those that aims to get a higher education in the nuclear field. In fact, promoting a proper skill transfer avoiding possible loss in the specific competences needed in the nuclear field is a strong commitment for LENA. The average visitor number per year is about 1500 students; LENA provided teaching activities for about 600 hours during the past three years.

**CONLUSIONS**

Experiences developed at LENA demonstrates how lecturing/training research reactors are extremely valuable for supporting nuclear culture both for education of new generation of students and researchers and for the training of professionals. Low and medium size research reactors within a university framework, like LENA, offer the best opportunity for the development of a national nuclear education & training system in connection with international institutions for the implementation of the most up to date safety standards.

Data from the last five years.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **2009** | **2010** | **2011** | **2012** | **2013** |
| N. Students from University | 22 | 30 | 10 | 72 | 73 |
| N. Students from Master’s Degree | 12 | 13 | 19 | 8 | 6 |
| N. final year students/trainees | 4 | 5 | 6 | 1 | 1 |
| N. Fellowship/Professionals | 3 | 48 | 5 | 1 | 3 |
| **TOT/Year** | **41** | **96** | **40** | **82** | **83** |

REFERENCES

[1] <http://www.unipv-lena.it/>

[2] Pavia TRIGA Mark II Reactor, *Nuclear test – Final Report*, University of Pavia,1965.

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[6] IAEA-TECDOC-1234 The applications of research reactors, 2001.