IMPLEMENTATION OF EUGENE WIGNER TRAINING COURSE AT UNIVERSITY "POLITEHNICA" OF BUCHAREST POWER ENGINEERING FACULTY NUCLEAR POWER PLANT DEPARTMENT

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Abstract. The "Eugene Wigner" training Course for Reactor Physics Experiments has been supported by the 5th Framework Programme of the European Commission, and it has been integrated in the ENEN (European Nuclear Engineering Network) program. This project has been prepared for the future European Nuclear Education schemes and degrees.
Starting from a general presentation of the course this paper presents my opinion as a former student about the course impact.
In this paper is written my opinion about the following:
- The content of theoretical courses,
- The usefulness of the textbook,
- The content of the practical experiments,
- The usefulness of the textbook for the practical experiments, and evaluations.

Moreover, parts of this course were implemented to my seminars. Results, expectations and conclusions about the usefulness of the course are presented.

1. Introduction

The Eugene Wigner Training Course is one of the results obtained by the ENEN Association (European Nuclear Engineering Network).
The course was opened to graduate and undergraduate students of any European university and it was carried out by four universities: University of Bratislava, University of Vienna, University of Prague and University of Budapest.
The course was divided in 3 weeks.
In the first week, all the students participated at the theoretical part organized by Slovak University of Bratislava.
The theoretical course was finished with an evaluation.
After that, the participants were divided into four groups for the practical exercises on research reactors carried out by Czech Technical University in Prague, Technical University Budapest, Technical University Vienna, and Atominstitute.

2. The theoretical part of the course

The theoretical course was held one week in Bratislava and carried out by the universities described above.
The theoretical lectures had the following topics:

- *Selected topics in reactor physics 1*. This topic outlined for the students the subcritical multiplication focused on neutron sources, effect of reactivity changes on subcritical multiplication; reactor kinetics focused on delayed neutrons, mean generation time with delayed neutrons and infinite reactor with delayed neutrons; response of a bare reactor to step change in reactivity, the prompt critical condition and reactor kinetic equations.
- *Selected topics in reactor physics II* was focused on the adjoint function and its applications: the adjoint transport equation, the adjoint diffusion equation and the perturbation theory.
- *Survey of research reactors* gave an overview about reactor utilization in physics, chemistry, medicine, academic research, training purposes and for industrial application.

- *Safety and control systems*. This topic was focused on the most important protection systems and design requirements, utilization of software in systems important to safety. Moreover it was presented the control and safety software of the VR – 1 training reactor (the reactor where it was done the experimental work in Prague).
- *Nuclear safety and physical protection of research reactors* gave an overview about nuclear safety, defence in depth on research reactors, safety culture, safeguards at research reactors, and emergency preparedness. Moreover, it was presented the nuclear safety rules for VR – 1 training reactor.
- *Outline for the lecture on health physics / radiation protection* was focused on dose definitions, dose limitations, dose measurement and determination; radiation protection activities at workplaces and radiation shielding.
- *Principles of detector operation* gave information about semiconductor diode detectors and germanium gamma – ray detectors.

All the topics presented in the theoretical part of the course were related to the practical exercises. The professors prepared nice and clearly presentation and they underlined the most important concepts. Moreover, the most important subjects were deeply presented for the best understand of the students.

Consequently, all the information provided by professors where concentrated in a textbook received by each student. Due to a big amount of knowledge, this course could not be studied deeply in a week. At the end of the course, an evaluation was performed. However, the subjects were not too difficult but because of the lack of the time our efficiency was not too good.

3. The content of the experimental work.

For the experimental work, the students were divided into 4 groups for the best efficiency of the practical experience. In each group, the participants came from different countries. In this way, we had the opportunity to meet and know different point of views of students due to different nationalities.

Each group had to perform a number of practical exercises in one of the above-described university. At the end of each practical exercise, the group had to write a report.

The main subjects of the experimental work developed are described below:

- In Vienna at Atomintitute we performed the following practical exercises:

(a) *Measurement of the thermal neutron flux density in the reactor core.* In this experiment, we measured the media flux distribution in the reactor place at the power of 10 Watt. The method of measurement was based on neutron activation analysis. Thin Au foils were irradiated in the TRIGA core at 10 W both Cd – covered and uncovered in different radial and axial positions. The radial and axial neutron flux distribution in determined from these Cd – difference measurements.

(b) *Control rod calibration and determination of the core excess reactivity*. In this exercise, the characteristic curve of the "automatic" control rod of the reactor was determined by removing it stepwise from the critical core and measuring the resulting reactor period. Using the in – hour equation the respective reactivity value was determined.

(c) *Determination of the importance function and the void coefficient*. In this experiment, it was determined the influence of volume and position in the core on reactivity by pulled axially a small container with different air volumes through the reactor core which was in an automatic operation mode at 10 W.

(d) *Criticality experiment.* In this exercise, we observed the criticality of the system. Ten fuel elements were removed from the reactor core and consecutively reloaded. The neutron count rate was measured after each step. At each step, measurements with all control rods up and then down are performed. Criticality was reached with all control rods up after reloading of five fuel elements.

(e) *Determination of the reactivity value of uranium fuel and graphite elements in different core positions*. While the reactor was on automatic control with 10W, one fuel element was removed from each of the five fuel ring positions. The movement of the regulating rod compensated the loss of reactivity. From the rod position difference and using the rod calibration curve the reactivity value of the fuel element in different core positions was determined. The experiment was repeated also with graphite elements.

(f) *Power calibration and determination of the temperature coefficient of the reactivity*. The reactor was operated at 10 W and rod positions, water and fuel temperature was noted. Then the reactor power was raised to 100 kW and the values were noted again. The fuel temperature coefficient was determined from the difference in rod position and fuel temperature. Then the reactor was operated for 90 min only with the convection cooling and the increase of waster temperature was monitored. Comparing the temperature increase with the value from a prevision calibration, the thermal reactor power was determined.

(g) *Demonstration of reactor pulses with different reactivity insertion*. In this experiment, the reactor power was raised to 10W with the shim rod and regulating rod. Then we switched the control instrumentation to "pulse mode", and the pulse rod was shot out of the critical core, and the power pulses took place.

- In Prague at Czech Technical University we performed the following practical exercises:

(a) *Properties of neutron detectors for nuclear reactor control*. In this experiment we determined the differential characteristic of the neutron corona detector of the SNM 10 and SNM 13 types, and in the second part we determined the dead time of the SNM 10 and 13 corona detectors by using the two source and maximum rate methods.

(b) *Digital control and safety systems of research reactors*. In this experiment were presented the most important VR - 1 system. The safety circuits represent an important part to ensure the nuclear safety. The reactor shutdown was based on the interrupt of the supply voltage for control rod magnets, which causes the loosening of the absorbers, and the fall of them into the core.

(c) *Start - up and operation of the VR - 1 reactor*. In this experiment we initialized and started - up the reactor. The start - up of the reactor, the operation of it was manual as well as automatic mode, the changes of the power (increasing, decreasing), the shutdown of the reactor for various reasons was demonstrated.

(d) *Measurements of reactivity by various methods*. There are more methods available to measurements the reactivity, such as, Source Jerk Method, Rod Drop Method, and Positive Period Method. We measured the reactivity using the Positive Period Method.

(e) *Calibration of control rods*. In this experiment, we determined the control rod worth by Rod Drop Method, and Source Jerk Method. Then from the upper end position, the rod was step - by - step adjusted into the selected positions and the rates were measured.

(f) *Study of nuclear reactor dynamics*. This experiment is divided in three parts:

i. Studying Influence of Bubbly Boiling to Reactivity. We observed the position of the rod response due to the reactivity changes because any change of physical parameters (coolant and moderator temperature) caused directly the reactivity change, and it works as a feedback.

ii. Studying the reactor response to the positive reactivity change. In this part of our experiments, we measure the transition characteristics of the reactor during the positive reactivity change.

i. Studying the reactor response to the periodic response reactivity change. In this experiment we observed the reactor power response to the two periodic reactivity changes, as a graphic on the screen in the control room.

At Budapest University of Technology and Economics, we performed the following exercises:
(a) *Determination of delayed neutron parameters and of uranium content of a sample*. Half lives and relative intensities of some delayed neutron groups were determined, then the ^{235}U concentration of a depleted uranium sample was estimated by comparing the delayed neutron intensities in the sample if interest and in uranium standard.
(b) *Determination of thermal neutron flux in the core in the reactor*. In this experiment, we determined the thermal neutron flux using activation method. Then the vertical reflector savings are determined. A wire of Dy - Al alloy containing 10% of Dy was used for the measurement of the neutron flux distribution. The absolute value of thermal neutron flux was determined by a gold activation detector.
(c) *Measurement of gamma and neutron dose rate*. This exercise was based on the proportionality between reactor performance and gamma and neutron dose rates. The ratios of the neutron and γ dose rate values were measured as a function of the reactor power level, at one of the horizontal beam tubes of the reactor.
(d) *Reactor operation exercise*. This exercise was made for students familiarizing with construction, operation and control systems of the nuclear reactors on different power levels. The goals of this exercise were: to learn how a nuclear reactor is controlled; to study the method of inserting or removing reactivity into or from the reactor core by moving the control and safety rods; to study and perform manoeuvres such as reactor start-up, power increase and decrease, automatic and manual operation, shutdown.
(e) *Determination of the reactivity worth function for neutron absorbers*. In this experiment it was used the rod compensation method for determining the reactivity. The reactivity importance of a perturbation was studied as a function of its position in the active core.
(f) *Neutron activation analysis*. The main objective was to identify some of the isotopes present in the given samples and to compute the mass concentration of some of these elements in the sample. The method used was neutron activation analysis.
(g) *Measurement of thermal neutron diffusion length in graphite*. In this experiment, the diffusion medium is graphite. The measurements were made in the thermal column of the irradiation tunnel of the reactor by activation method. The measurement was made in the graphite thermal column in the irradiation tunnel of the reactor.
For each student it was provided a textbook for each practical laboratory.
The content of textbooks was usefulness for a good evolution of the experimental work. There was a good logic between the theoretical part of the experiment and the practical exercise and the most important concepts were underlined at the beginning of each exercise through *"Theoretical background"* and *"Theory of experiment"* paragraphs. In this way, the students had the opportunity to study deeply the most important keynotes.
Moreover, the textbooks gave indications for performing the experiments to obtain the best results. At the end of each exercise there was a paragraph *"Knowledge check"* or *"Results expected from the students"* which helped the students in their reports preparation.
The reports prepared by each group had to be presented at the end of each practical exercise. It was very interesting to have international teamwork for reports preparing. Every student gave her/his idea about what it had to be writing in the reports and finally we performed, after my opinion, relevant reports.

4. Cost of the course.

The cost of the course (3 weeks) was established at 2100 €, which included the tuition fee, textbooks, the accommodation during 3 weeks period and the transport between the four countries.

In my case, without the gratefully support of IAEA (International Atomic Energy Agency), ROMATOM (Romanian Atomic Forum) and AREN (Romanian "Nuclear Energy" Association) I could not joined the Eugene Wigner Training Course. And there were more east – European students in my situation.
Moreover, the course gave students the opportunity to develop new knowledge and skills on research reactors through the experimental work performed.
As well, it was very attractive to work in an international team, to share with students from other countries my experience and to learn from other experience.
Therefore I consider this course usefulness for a young graduate or undergraduate nuclear student. Consequently it would be appreciate if in the future more nuclear companies will be involved in the financial support of the course. In this way, maybe, more students or young assistant – professor, like me, can benefit for a very useful and attractive course like "Eugene Wigner" Training Course.

5. Implementation of "Eugene Wigner" Training Course at University "Politehnica" of Bucharest – Power Plants Faculty – Nuclear Power Plants Department.

As a result of this course, I was nominated to hold seminars at our department in the field of Reactor theory.
"Eugene Wigner" Training Course helped me to understand deeply the importance of this course. Therefore, I implemented the most important practical exercise as theoretical problems to my seminars.
Due to the lack of training reactor in our university, our students learn a lot of nuclear theory. They have a practical period at the end of the eighth semester at NPP Cernavoda but they can not perform any exercise. Moreover two week of practical period is a short period to deepen what they learned in eight semesters.
Accordingly to this, I tried to present the experimental work performed on research reactor at "Eugene Wigner" Training Course as theoretical problems solved with the methods, which I used in the course.
Because I had only 1 hour / week I focused my seminar to practical exercises performed at Atominstitute due to the closer topic with our reactor theory syllabus.
In this way, I could give an attractive seminar and my students developed the importance of the course and the importance of the comprehension of the equations and the workability of their solutions in the practical work. At the end of the seminar, they had with 10% higher qualifying than last year and the grade of the exam was 10% higher than last year.

REFERENCES

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