Upgraded Practical Training for Students of Nuclear Sciences at CTU-FNSPE

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INTRODUCTION

The public image of nuclear sciences and technologies is problematic, for many reasons. Major nuclear accidents, especially at Chernobyl and Fukushima, have raised the demand for nuclear and radiation safety to extreme levels. However, the first generation of highly qualified nuclear specialists has gone or will soon go into retirement, and there is a shortage of younger university graduates to replace them, both in countries with a long tradition of nuclear engineering and in countries that now experience a need for well-qualified nuclear engineers for power production, industry, medicine or research. Even the European Commission has pointed out this disappointing reality in the Euratom programme for 2014-15 [1]. Moreover, education and training in this field is demanding and costly, as specialists dealing with nuclear issues and ionizing radiation take on extreme responsibilities, and improper operation can lead to a serious accident. In recent years, a trend toward “computerisation” has been evident among students of technical and natural sciences. They tend to model all processes on computers, and when a good model has been made and tested, they consider their work to be done. However, this approach is not adequate in the nuclear sciences, where everybody engaged in

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the work needs to acquire real experience in handling nuclear radiation and in nuclear and radiation safety.

The Faculty of Nuclear Sciences and Physical Engineering of the Czech Technical University in Prague (FNSPE) is the only university institution in the country that teaches and develops a broad range of studies in the field of nuclear sciences. The Faculty has its own small nuclear reactor and a small tokamak. The rapid development of nuclear physics and chemistry and their applications, and also ongoing efforts to achieve the highest possible levels of nuclear and radiation safety, have led to a need for advanced practical training for students. Practical exercises and work in the laboratory therefore form an important part of the study programme. Nuclear instrumentation for training students should keep in contact with the current state of the art. The instrumentation that is used has been progressing rapidly, and training facilties need to be modernised at frequent intervals. With limited university budgets, this is not an easy task. A project was therefore applied for within the framework of the Prague Adaptability Operational Programme, supported by European funding. This project aims to improve the quality of studies in educational institutions in Prague, and has been used to upgrade the laboratories for practical training of students in five departments of CTU-FNSPE. A total of 24 exercises for measuring and evaluating various quantities have been upgraded or newly prepared, ranging from the characteristics of nuclear reactor kinetics, through the design of electronic circuits for nuclear measurements, ionising radiation spectrometry, measuring the absorbed dose, detecting radioactive contamination, to topics such as the use of radiation diffraction in the study of materials. We will review here the innovations that are being made, and we will discuss the requirements and the structure of the practical exercises

1 GENERAL CONCEPT OF PRACTICAL TRAINING IN THE NUCLEAR LABORATORIES OF CTU-FNSPE

The Faculty of Nuclear Sciences and Physical Engineering (FNSPE) is divided into ten departments; five of them are fully or partially oriented to nuclear and radiation issues. The names of these five departments and the fields of study that they cover indicate the range of topics covered by the Faculty:

- The Department of Physics, the largest of the participating departments, offers a basic course in physics, and is also responsible for the study programmes in Experimental Nuclear and Particle Physics, and in Physics and Technology of Nuclear Fusion. The department also operates the small training tokamak.
- The Department of Dosimetry and Application of Ionising Radiation offers a study programme under the same name as the department itself, and is also responsible for Radiological Physics, which covers all ways in which ionising radiation is used in medicine – in radiotherapy, radiodiagnostics and nuclear medicine.
- The Department of Nuclear Chemistry covers all aspects of nuclear chemistry and its applications (also in biology and medicine), including environmental chemistry.
- The Department of Nuclear Reactors operates the small VR-1 training reactor. The work of the department is based on this unique equipment. Theory and technology of nuclear reactors and nuclear reactor operation are supplemented by courses on nuclear and radiation safety.
- The Department of Solid State Engineering deals with a broad spectrum of problems in applied solid state physics, including some problems related to ionizing radiation, especially materials for solid state detectors of radiation and applications of X-ray and neutron diffraction.

An in-depth explanation of physical problems “at the blackboard” is followed by practical exercises and training. For a better picture of the teaching concept, let us mention three examples of textbooks that correspond well to the needs of our Faculty and indicate the depth of knowledge needed for a good understanding of some of the tasks included in the practical exercises: we use Mukhin’s classical textbook [2] or the slightly simpler book by J. Lilley [3] for basic nuclear physics, and Knoll’s well-known monograph [4] for working on the detection of ionising radiation.

The practical exercises arranged by the five departments at FNSPE cover the regions of interest of each of the departments. The credit system allows students, in principle, to select exercises in subjects taught not only by their own department, but anywhere at the Faculty. Unfortunately, this system has some limitations, partly due to the differing prerequisite knowledge for various tasks and also partially due to the times at which various subjects are taught. In practice, students use this option only to a limited extent.

In general, each of the practical exercises involves some home study of the topic and requires three or four hours of measurements in the laboratory, followed by further homework on processing and evaluating the results. A detailed manual is provided for each exercise. Students usually work in groups of two or three, and they take ten to twelve exercises in a semester. The amount of time that students should spend on these exercises varies. For nuclear chemistry, as the maximum, there are 8 hours of direct laboratory work weekly (and 8 credits are awarded) in the winter semester and 6 hours of direct laboratory work weekly (and 5 credits) in the summer semester of the third year of the bachelor study programme. The reports from these exercises are evaluated and classified on the same grading scale as for standard courses.

This system of practical exercises is supplemented by other forms of training. Semester projects usually begin in the second year of bachelor programmes, when the students mostly carry out a literature search and evaluate their findings. For the bachelor thesis in the third year of study, students are required to make some scientific contribution of their own through experimental or computational work. Year-long projects and theses at master level require students to carry out some substantial research work. In ideal cases, when the topic of the student's thesis in the final year of her/his master's programme is related to the theme of the project carried out in the previous year, the thesis can be on a high enough scientific level to be submitted as a paper for a scientific conference or for a scientific journal, often at international level. However, there are too many students and too many projects for the Faculty itself to provide, and a lot of collaboration with external institutions is needed (the contacts and close collaboration made in this way often help a fresh graduate to find a good job). The number of credits awarded indicates the high importance given to this practical training. Bachelor students earn 19 credits for practical exercises, and master's students earn 44 credits.

Many industrial managers complain that, in general, graduates from technical universities have received a good theoretical preparation, but that they are not ready for the demands of practical applications when they take up their first job. We have extended the practical training offered at FNSPE as much as possible, and we are pleased to be able to say that we have never heard any complaints about the practical skills of our graduates.

2 EXAMPLES OF EXERCISES

In order to give some idea about the variety of tasks included in the practical exercises on nuclear sciences and ionising radiation, we will summarize some selected examples in this section. It would not be practical to provide a complete list here (it can be found on the web page of the Faculty www.fjfi.cvut.cz), and we also cannot give a detailed description of the tasks in each exercise. However, we trust that the following list of selected titles will give the reader and adequate idea. Please forgive us for putting these examples in no particular order (which could scarcely be done in a meaningful way). We think the reader will recognize which exercises are of a basic character, and which are highly specialised:

- Scintillation spectrometry of gamma radiation
- Liquid scintillation spectrometry
- Monitoring the statistical nature of radioactive decay
- The range of alpha particles in a material
- The spectrum of X-rays from a tube with a Mo anode
- The Zeeman effect
- The increase in indium activity in dependence on the time of irradiation by neutrons; determining the half-life
- Experimental devices for X-ray and neutron diffraction analysis
- Application of neutron diffraction for determining textures
- X-ray radiography of thermal stress relaxation
- Determining gamma emitting radionuclides in environmental samples
- Applications of atomic absorption spectroscopy
- Applying an electron microscope for investigating the surface and microstructure of solid state materials
- Determining the absolute amount of beta radionuclide from its beta activity
- Determining the half-life of long living radionuclides (^{40}K, ^{238}U)
- Radiation dechlorination

- Radiation polymerization
- The influence of ionising radiation on microorganisms
- Determining the radiochemical purity of a compound labelled by radiocarbon
- Determining the solubility of low-solubility compounds using radioactive tracers
- Radiochemical determination of ^{137}Cs in natural waters
- The Fricke dosimeter
- Thermoluminescence dosimetry
- Gamma beam attenuation and scattering
- Characterisation of X-ray beams and dose measurement in the beams of various X-ray machines
- Monitoring gamma beams of ^{137}Cs in phantoms by various detectors
- The Eclipse 3D planning system for calculating clinical treatment planning, and analysis of the data
- X-ray fluorescence analysis
- Experimental methods for determining neutron-physical and basic operational parameters of nuclear reactors
- A critical experiment at the teaching nuclear reactor
- Measurements of neutron diffusion in various materials
- Determining the characteristics of delayed neutrons
- Preparing and characterizing photoneutron sources.

This, of course, is far from a complete list, but we think that these 33 examples are sufficient to give the reader an idea about range of practical problems and exercises offered to students.

Keeping this system up-to-date is, of course, very costly. We have therefore welcomed the opportunity to obtain grants from the Prague Adaptability Operational Programme, financed by the EU. Though the financial support from this programme has been limited, it has allowed us to upgrade 24 exercises by buying new instrumentation and contributing to the salaries of the staff that have prepared this upgrade. We will deal with this contribution in greater detail in section 4 of this paper.

3 CASE STUDY: EXAMPLE OF THE STRUCTURE OF A TEXT FOR STUDENTS

Here we will show the structure of a text for preparing students for an exercise. We take the simple example of measuring the dead-time of Geiger-Müller counters (we will not give the full text, as it would be too long and only of limited interest for non-specialists). GM counters are relatively simple pulse detectors of ionising radiation. They have no spectrometric capability, but are resistant and have a simple and inexpensive electronic evaluation device. This is why they are still used, especially in applications in harsh environmental conditions. They have a longer dead-time (the time after a registered pulse, when the counter “recovers” and cannot detect a pulse from another particle) than most other types of radiation detectors. This makes them an ideal tool for explaining what the dead-time is and how to determine it.

The introductory theoretical part of the manual for the exercise presents facts about GM counters and their dead-time, which the students should be familiar with from lectures on radiation detectors. However, as the Czech proverb says, “repetition is the mother of wisdom”. The text then focuses on the heart of the exercise, i.e. methods for determining the dead-time. The most widely-used method, with two radiation sources, is described in detail, including a mathematical derivation of the corresponding formula, and the principles of the strong radiation source and time spectrometry methods are also outlined.

The subsequent part of the exercise deals with practical implementation of the measurements. It summarises the requirements for all methods for determining the dead-time, i.e. radiation sources (^{60}Co) and electronic devices, electronic connections between various parts of the measuring apparatus and recommended settings of the instruments (in more complicated cases, this is supplemented by a schematic representation), and the measurement tasks (which we will give in full):

- Choose a good-quality GM counter (the selection is based on the results of another exercise on the basic properties of GM tubes).
- Use the method of two radiation sources for measuring the dead-time at the beginning, in the centre, and at the end of the plateau.

- Determine the dead-time by the strong radiation source method for 10 values of the voltage between the beginning and the end of the plateau of the same GM tube.
- Measure the time spectra of the intervals between two pulses using the time-amplitude convertor for 5 voltage values between the beginning and the end of the plateau of the same GM tube.
- Determine the dead-time from these spectra for various voltage values.
- Measure the distribution of pulses from the same GM tube in time using the multi-channel scaling system for 10 different voltages between the beginning and the end of the plateau.
- Determine the dead-time from these distributions for various voltage values.
- Process the results of all measurements graphically; discuss the reasons for the dependence on voltage and the shape of this dependence; discuss differences between the results obtained by various methods.

Methodological instructions for teachers form an integral part of the documentation for this exercise. The instructions help the teachers to supervise the work of the students and to prevent serious errors, which can cause the measurements to fail, or can even damage expensive instrumentation.

4 UPGRADING WITHIN THE FRAMEWORK OF THE CURRENT PROJECT

The city of Prague is classified by the European Union as a rich region with a developed infrastructure, and the city therefore has very restricted access to European funding. This is a handicap for the Prague-based universities. However, we are eligible for some limited money from the Prague Adaptability Operational Programme, which includes some support for improving the training of specialists. This Operational Programme is managed by the Prague municipality and is funded partly by the EU and partly by the Czech side. The project under the title “Upgrade of practical training of students in nuclear engineering at CTU-FNSPE” has helped us to add to and substantially modernize 24 exercises of the type described in sections 2 and 3. The innovations have focused mostly on sophisticated methods and exercises. Let us summarise them:

The first circle of exercises deals with nuclear reactors:

- An investigations of Cherenkov radiation in swimming-pool type nuclear reactors.
- An investigation of the basic characteristics of the kinetics of zero power reactors.
- Reactivity and reactivity measurements in low power reactors.
- The VVER-440 simulator – Compensation of fuel burning by changing the concentration of boric acid, controlling the power of a reactor block.
- The VVER-1000 simulator – Accidental situations at the nuclear reactor.

The second circle of exercises is related to ionising radiation measurement techniques as a necessary aspect of experimental nuclear science and technology:

- Anti-Compton shielding in gamma radiation spectrometry.
- The coincidence method of absolute measurements of the activity of radionuclides.
- Application of time spectrometry for determining the dead-time of a detector, for measuring the statistical character of radioactive decay, and for replacing coincidence measurement.
- Signal shape analysis as a tool for identifying types of ionising radiation particles.
- Methods for determining the dead-time of a detector (this exercise was presented as an example in the case study in section 3).
- Methods for measuring the absorbed dose.

Closely connected with detection techniques, the third circle deals with electronic systems for processing and evaluating signals:

- Design and realisation of basic electronic circuits for nuclear measurements.
- Amplifiers, timers, signal shaping, discriminators.
- Data collection systems, multi-channel analysers and their calibration.

Due to the close relation between nuclear physics and nuclear chemistry, some students of nuclear engineering need to be able to work in a radiochemical laboratory. The following experiments are aimed at them:

- Techniques for detecting radioactive contamination, and principles of decontamination techniques.
- Principles of photochemical and radiochemical instrumentation
- Spectrometry of alpha radiation and techniques for sample preparation.
- Liquid scintillation spectrometry – variants using multiple photomultipliers.
- Instrumentation and detection techniques for separation using liquid extraction.
- Instrumentation for chromatographic techniques – from preparing chromatographic columns to High Performance Liquid Chromatography.

Last but not least, the whole set of exercises is supplemented by work on the material properties of materials and their interaction of with radiation:

- Computer simulations of radiation effects in materials.
- Characterisation of the parameters of materials, especially for use in the design of semiconductor radiation detectors.
- Application of absorption and diffraction of X-rays.
- Applications of neutron diffraction.

Some of these exercises were also listed section 2. The reason for this duplication is simple; they are not completely new exercises, but support from the project has enabled them to be modernized substantially.

5 SUMMARY AND ACKNOWLEDGMENTS

As was briefly mentioned in section 1, the practical exercises carried out mostly in the laboratories at the Faculty that we have focused on here form only a part of the complex of practical education and training of nuclear specialists at FNSPE. However, the practical exercises are an important aspect, because they represent the first practical contact with ionising radiation for most students (it would be possible to write about radiation safety in the laboratories, but this would be another story). It should also be pointed out that the exercises give students a wide overview of problems and methods in applied nuclear sciences and technologies. Other aspects of practical training, i.e. project work carried out by students, including their bachelor and master theses, often carried out in collaboration with some external institution, give them a deep insight into a single problem. In these practical exercises, they learn how to solve problems and overcome difficulties, how to write a complex report, and they also acquire the basic ability to work in a nuclear laboratory, to control an experiment, to process and evaluate data. This is why the Faculty places so much emphasis on this type of teaching. And this is also why we decided to share our experience with the readers of this paper.

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