Teaching and research in radiological physics – linking engineering, science and medicine

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INTRODUCTION

For centuries, physicians were absolute sovereigns in their discipline. However, the situation started to change when various sophisticated instruments came into medicine, i.e. approximately from the beginning of the 20th century. The invention of X-ray machines, accelerators, lasers and other devices and their introduction into medical practice have pushed medicine into its borderland with the hard sciences and with engineering. Medicine, especially in its highly specialised branches, has become an interdisciplinary field, with unavoidable relations not only to biology, but also to physics, chemistry and informatics. Medical physicists have become important and equal partners for physicians (a fact that some physicians, unfortunately, have had difficult in understanding or accepting). The need for highly qualified physicists and technicians in medicine has also been reflected in the study programmes of some technical universities, including the Czech Technical University in Prague (CTU), especially at its Faculty of Nuclear Sciences and Physical Engineering (FNSPE). This faculty teaches a range of programmes for technicians and physicists in medicine. It offers a bachelor programme in Radiological Technology, and MSc and PhD courses and programmes in Radiological Physics. We will deal here with the MSc study programme in Radiological Physics.

1 GENERAL FEATURES OF RADIOLOGICAL PHYSICS

1.1 Medical use of ionising radiation

Medical uses of ionising radiation, the field for which physicists are prepared at FNSPE, can be divided into three areas: radiation diagnostics (using external radiation beams), radiotherapy (using external radiation beams or internal radiation sources in the case of brachytherapy), and nuclear medicine (using internal radiation sources both for diagnostics and for therapy). The medical staff who plan and implement the medical exposures of patients bear extraordinarily high responsibility, as the approach to radiation exposures in medicine differs from the approach to radiological protection in other planned exposure situations [1]. Medical exposure is intentional, and is for the direct benefit of the patient. This means that there are no fixed limits on exposure, as in the case of occupational exposure and exposure of the public. In radiation therapy, the biological effects of high dose radiation (cell killing) are used to treat cancers and other diseases. This involves delivering the required dose precisely to the site that is to be treated, avoiding unnecessary exposure of healthy tissues. In diagnostic procedures, this requires a balanced compromise between best diagnostic information and minimum exposure of the patient. In all these cases, there is no limit on the effective dose to the patient, and the dose depends only on the procedure and its usefulness for the patient.

Planning the radiation doses to patients, controlling the instrumentation, dosimetry and quality assurance cannot therefore remain only in the hands of physicians. Radiological physicists have become unavoidable partners in the whole process; in many countries they are included in the national legislation (see [2] for legislation in the Czech Republic). Though the final responsibility for the medical exposure of patients lies with a physician, technical implementation and avoidance of unnecessary irradiation are matters for a physicist. Both partners, physician and physicist, should therefore be trained in the principles of radiation protection, including the basic principles of physics and biology.

1.2 Demand for the education of radiological physicists

The study programme in radiological physics must cover three different areas: radiation diagnostics, radiotherapy and nuclear medicine, at a mutually comparable level. This implies a strong requirement to include a wide spectrum of medical courses in the technical education of a physicist. Sufficient knowledge of such medical fields as biochemistry, anatomy, physiology, pharmacology, ethics in health care, etc., needs to be included in the programme. At the same time, as a necessary prerequisite, the programme must give students a firm background in mathematics and physics, and in the principles and the instrumentation for measurements. This broad spectrum of subject matter means that the programme cannot be taught only by an engineering faculty, but needs broad collaboration with specialists from medical faculties and hospitals. Nevertheless, we must bear in mind that we are educating applied physicists, on the border between physics and engineering. They need to have sufficient knowledge of medical disciplines to communicate with physicians, but the physicians are not educated by us. For radiological physicists, though not for physicians, mathematics and physics must remain key aspects of the study programmes. This is sometimes a problem in discussions with physicians. We must of course discuss the content of our study programme with them, but they tend to give excessive priority to medical skills, and not to appreciate the importance of physical and technical aspects of our programme.

Who are our “customers” - the institutions that employ our graduates? In the first place, they are clinics and departments of radiotherapy in hospitals. The Regulations on Radiation Protection [2] specify that the staff of any radiotherapeutic workplace, including radiotherapeutic departments of nuclear medicine must include a radiological physicist. This demand is less strict for radiation diagnostic workplaces, where a radiological physicist need not be a direct member of staff, but must be available, and her/his role must be included in the quality assurance programme (with some insignificant exceptions, e.g., for dental X-ray equipment). Some graduates can also find employment with the radiation protection authorities, especially at the level of the State Office for Nuclear Safety and its National Radiation Protection Institute, in some research institutions, at universities, etc.

2 THE MASTER PROGRAMME IN RADIOLOGICAL PHYSICS AT CTU-FNSPE

2.1 General characteristics of the programme

Due to the need to cover a broad spectrum of topics, the MSc programme in Radiological Physics, lasts three years. Students who enrol are expected to have a wide knowledge of mathematics and physics. In mathematics, this knowledge should cover mathematical analysis, linear algebra, differential equations and numerical methods. In physics, it should include mechanics, electricity and magnetism, thermodynamics and statistical physics, physics of molecules, optics and atomic physics, and some basic theoretical physics. These prerequisites are met by a good bachelor degree programme at a research-type engineering faculty, or by a bachelor programme in mathematics or physics (e.g. at FNSPE).

The study programme itself supplements this education in mathematics and physics with mathematical physics, probability and mathematical statistics. The study of physics is oriented towards nuclear radiation. It consists of a basic two-semester course in experimental nuclear physics, and further quantum physics, principles of dosimetry and detectors of ionising radiation, integrating dosimetric methods, nuclear instrumentation (including large radiation sources – nuclear reactors and accelerators), Monte Carlo calculations in radiation physics, radiation protection, radiation metrology, and processing of measured data.

Further topics are on the boundary between physics and medicine, or, more exactly, they deal with physics in direct application to medicine. The key topic, radiological physics, is divided into three parts – physics in X-ray diagnostics, physics in nuclear medicine, and physics in radiotherapy. There are lectures on clinical dosimetry, information sciences in medicine, and recognition and processing of images.

The course in clinical propedeutics offers an introduction to biological and medical topics. During the first year of study, this course is supplemented by the principles of human anatomy, biology and physiology. Further “non-engineering” topics in the second and third year of study are: ethics in medicine, hygiene and epidemiology, biochemistry and pharmacology, principles of first aid, pathology, anatomy and physiology, and technical and medical legal regulations.

This extensive programme is the outcome of long discussions and negotiations between the technical university, which has pushed the orientation as much as possible towards physics and engineering, and physicians, who have pushed the orientation as much as possible towards medicine. Though students are not burdened in the final version of the study programme with courses on, for example, “the work of nurses at the bedside”, they have quite a lot of hours of lectures and exercises (more than 30 per week). In addition, they have practical training and the possibility to choose some optional courses.

2.2 Practical training

The basic practical exercises are carried out in the laboratories at the Faculty. They comprise some general radiation measurements with various detectors and dosimeters, including gamma spectrometry, as well as some medically-oriented exercises. We will provide a few examples.

One of the exercises deals with the parameters of a diagnostic X-ray beam, its collimation, filtration, and material half-value layers. Students can also learn more about this problem from the “classical” paper on this topic [3]. Another exercise involves measuring kerma in conditions of medical exposure, i.e., in the beam impacting the surface of a phantom simulating a human body. In this way, students obtain basic practice in making measurements with an ionisation chamber calibrated for medical radiography. They can extend their knowledge, for example, by reading Dosimetry in Diagnostic Radiology: an international code of practice [4], which is recommended reading for students. This publication serves as a guide for another exercise – determining the dose absorbed in the mammary gland during a mammographic examination. Exercises of this kind can be carried out easily in any radiation laboratory. They do not need sophisticated and expensive instrumentation, which a technical university without its own medical faculty and university hospital would be unable to provide.

Graduates must become familiar with the current state-of-the-art and with modern instrumentation in radiotherapy, nuclear medicine and radiation diagnostics, not only through lectures, but also through practical experience. Instrumentation of this kind (medical accelerators, the Leksell gamma-knife, production of radiopharmaceuticals, the gamma camera, positron emission tomography, etc.) is too expensive to make available only for teaching purposes. Wide collaboration has therefore been established with leading Prague hospitals, and students have clinical practice in all three branches included in their programme. They spend two weeks in radiotherapy, two weeks in nuclear medicine, and two weeks in radiodiagnostics. A part of this practice takes only the form of visits to hospital departments, but students also work under the supervision of experienced radiological physicists. Let us mention a few examples of problems that they deal with: absolute and relative dosimetry of photon beams, planning for radiotherapy, verification of intensity-modulated radiation therapy, quality assessment of a multileaf collimator, tests of operational stability in mammography, controlling a computer tomograph, production of radiopharmaceuticals for positron emission tomography, application of ^{131}I and its special features. This is only a selection: the whole list consists of 32 topics in five hospitals.

2.3 Research work and thesis

In parallel with the lectures, exercises and practical work summarised in sections 2.1 and 2.2, the students are also involved in project work. They start with projects in the first year of the study programme. However, this is only a preparatory phase, in which they acquaint themselves with the problem they will work on over the next two years and which will be the subject of their thesis. They also make a search for suitable publications and evaluate them; in some cases they also carry out some preliminary experiments. In the ideal case, the report from this work can serve as the first draft for the introductory part of their thesis, summarising the state-of-the-art.

In the second year, students should make a much greater individual contribution, carrying out and evaluating some experiments, etc. The report thus takes on the character of a “small thesis”.

The final thesis is elaborated during the third year of the programme. Since the student works on the same topic over a long period of time, the thesis can be on a high level, often with results eligible for publication in a scientific journal or for presenting at a conference. There is often fruitful collaboration with an external medical institution through thesis supervision and other work done by students. For illustration, let us give some titles of theses presented in the last two years:

- Influence of the calibration curve of CT on the accuracy of irradiation plans in radiotherapy.
- Optimisation of the shape of a multileaf collimator for a cobalt irradiator by the Monte Carlo method.
- In-vivo dosimetry of electron beams based on semiconductor diodes and radiochromic films.
- Examination of doses from secondary radiation in proton therapy.
- Determining the radiation exposure from an examination of the colon using a Ga-citrate.
- In-vivo dosimetry in brachytherapy.
- Effects of ionizing radiation on the ability of enzymes to break down plasmid DNA.

Between five and eleven students have graduated each year as radiation physicists.

3 SWOT ANALYSIS

3.1 Strengths

Radiological physicists are “scarce goods”. Due to the introduction of new methods and new instrumentation, and also due to Czech legislation, hospitals urgently need them. The graduates do not need to worry about failing to find a proper job in their field of specialization.

CTU-FNSPE is the only faculty in the country that offers a study programme of this kind. It is very demanding both on teachers and on equipment, and it would not be easy to prepare a similar programme of comparable quality. Commercial private universities, which have been growing in the Czech Republic like mushrooms after the rain, concentrate almost entirely on softer specialisations and would not be able to consider offering such a programme.

The high quality of the programme is guaranteed by wide collaboration among physicists from FNSPE and physicians from medical faculties of Charles University in Prague. Collaboration of leading Prague hospitals in the practical aspects of the programme, and in supervising project theses, is also an important contribution. Interdisciplinary programmes of this type correspond to modern trends and cover topics that cannot be included in traditional programmes at higher educational institutions specializing in engineering.

The programme is not only accredited by the Accreditation Commission at the Ministry of Education, but is also recognized by the Ministry of Health. This means that the graduates are accepted at the same level of seniority as physicians in the “hierarchy” of workers in medicine (this is not self-evident in the Czech Republic, and was not usual in the past).

Themes for master's projects are usually chosen in such a way that they have a strong relation to real practical problems. Nevertheless, they are on a high scientific level and many of them can be expanded and developed into the topic for a PhD dissertation.

Unlike many other programmes at technical universities, this programme is "gender balanced". About one half of the students are women.

3.2 Weaknesses

The programme poses heavy time demands and intellectual demands on the students. Not every student has the required range of skills in mathematics and physics, biology and medicine. Though there is more interest in enrolling in Radiological Physics than in many specialisations at technical universities, the number of graduates does not meet the needs of medical institutions.

From the organisational point of view, it is difficult to put together the time schedule. It is difficult to coordinate the calendars of teachers from various institutions, and it is necessary to balance the need of hospital departments to carry out their work with patients with their ability to provide practical training for students.

Specialists from a wide range of fields feel competent to comment on the structure of the programme, and to ask for the composition to be shifted more towards their own field of specialization. There is a constant need to keep a balance between physical and technical courses, on the one hand, and biological and medical courses, on the other. Fortunately, great help is provided by the Czech Association of Medical Physicists, which also contributes substantially to promoting the programme and gaining professional recognition for it.

As the programme is taught by teachers not only from FNSPE, but also from other institutions, the staff costs for external lecturers are higher than for usual programmes that have a lower proportion of external collaborators. The material expenses for a programme of this type are also relatively high.

Typical MSc programmes take two years. Ours is a three-year programme. This means that the standard length of studies for an MSc degree, which must include three years of bachelor studies, is six years. The length can be slightly reduced by the fact that bachelors graduating from FNSPE, and who decide in time to continue in this MSc programme, can take some of the master's courses in the third year of their bachelor programme, and can graduate with a master's degree within five or five and half years. However, this possibility is not open for bachelors from other universities and faculties.

3.3 Opportunities

The programme expands the activities of the technical university into an interdisciplinary field, and can thus attract young people who might otherwise not have considered engineering studies.

Collaborating with medical and biological institutions enhances the professional experience of our staff, and extends the fields of possible research activities, with a guarantee that the studies and investigations will find use in practical applications.

A high-quality programme of this type raises the prestige of the university, with the general public and also with specialists in engineering and in medicine.

Radiological physics is a branch of science with a long history in the international environment, beginning with the 1st International Congress of Radiology in 1925 in London. Intensive exchange of experience and optimization practices is carried out, and international societies of physicists in medicine are well organised and influential. Activities in this field therefore provide new opportunities for interesting international contacts and collaboration.

Medical aspects of ionising radiation can help to improve the negative view of the public toward everything somehow connected with “atomic” or “nuclear” or “radiation”. Even Greenpeace activists may one day need an X-ray examination, or be treated at a clinic using radiation!

3.4 Threats

There is strong competition among Czech higher educational institutions, fuelled among other things by long-term underfunding of education in the country, and by the system of whereby funds are distributed among the universities to a considerable extent on the basis of student numbers. The success of our study programme could give rise to the idea of preparing an apparently similar programme, but easier, with less mathematics and physics, and to lobby hard for its accreditation. As most young people nowadays are not attracted by the hard sciences, this type of programme, offering an easier but lower-quality way to gain an academic degree, could lure potential students away.

As our programme is expensive to provide, it might in future suffer from inadequate funding, or a cheaper alternative might be favoured.

All collaborative enterprises are based on good personal relations. These can be influenced by key persons retiring or moving to another position. It can be difficult and time-consuming to seek replacements for key teachers and valued supervisors for practical training.

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