

# Outline of the 2019 DTU Nutech Medical Radiation Dosimetry Course

Revised: July 7, 2018

## Abstract

DTU's post-graduate "Medical Radiation Dosimetry Course" provides the theoretical and metrological background for measurement of radiation doses in radiotherapy, diagnostic radiology, and nuclear medicine. The five-day intensive course is based on the revised version of the classic textbook by F.H. Attix published in 2017 by P. Andreo et al.. The key elements in the course are:

- Interaction between radiation and matter
- Cavity theory
- Monte Carlo calculation of radiation transport
- Radiation detection techniques
- Metrology (traceability and uncertainty)

Although the course is mainly theoretical, the following specific types of dosimetry will also be discussed:

- Reference dosimetry in MV x-ray and electron beams in accordance with the IAEA TRS-398 code of practice
- Dosimetry for kV x-ray beams
- Internal dosimetry
- Introduction to proton beam dosimetry
- Introduction to dosimetry in MR-linacs

The course will be presented by researchers from DTU Nutech (Center for Nuclear Technologies, Technical University of Denmark, Risø Campus, Roskilde, Denmark). The 2019 course will be given in English and international participants are welcome. The course has been given annually since June 2010, so in 2019 we will provide this course for the 10th time.

## Contents

<b>1 Disclaimer</b>	<b>2</b>
<b>2 Course web site</b>	<b>2</b>
<b>3 Course title</b>	<b>3</b>
<b>4 Course dates</b>	<b>3</b>

<b>5</b>	<b>Number of participants</b>	<b>3</b>
<b>6</b>	<b>Deadlines</b>	<b>3</b>
<b>7</b>	<b>Course textbook and materials</b>	<b>3</b>
<b>8</b>	<b>Learning objectives</b>	<b>4</b>
<b>9</b>	<b>Teaching methods</b>	<b>4</b>
<b>10</b>	<b>Intended audience</b>	<b>5</b>
<b>11</b>	<b>Pre-registration</b>	<b>5</b>
<b>12</b>	<b>Registration</b>	<b>5</b>
<b>13</b>	<b>Cancellation and payment</b>	<b>5</b>
<b>14</b>	<b>Course price</b>	<b>5</b>
<b>15</b>	<b>Computers</b>	<b>6</b>
<b>16</b>	<b>Preparation</b>	<b>6</b>
<b>17</b>	<b>Location and maps</b>	<b>7</b>
<b>18</b>	<b>Public transport</b>	<b>7</b>
<b>19</b>	<b>Accommodation</b>	<b>7</b>
<b>20</b>	<b>Language</b>	<b>8</b>
<b>21</b>	<b>Instructors</b>	<b>8</b>
<b>22</b>	<b>Outline of course sessions</b>	<b>8</b>

## **1 Disclaimer**

This is an outline of the course. Adjustments (not yet described in this document) may be implemented in the actual course.

## **2 Course web site**

This is a shortcut to the course web site:

`www.mrdc.dtu.dk`

The full address is:

`http://www.nutech.dtu.dk/english/research/dosimetry/medical-dosimetry/medical_radiation_`

For the electronic version of this document, you can also click here. Alternatively, go to the main DTU web-site ([www.dtu.dk](http://www.dtu.dk)) and navigate to the site for the center: "DTU Nutech".

### 3 Course title

- Medical radiation dosimetry course

### 4 Course dates

- From May 20 (Monday) to May 24, 2019 (Friday)

### 5 Number of participants

- Minimum number of participants: 6
- Maximum number of participants: 12

### 6 Deadlines

- April 15, 2019: Registration deadline.

### 7 Course textbook and materials

The course is based on the following main text (referred to as FIORD):

- P. Andreo, D.T. Burns, A.E. Nahum, J. Seuntjens, F.H. Attix: Fundamentals of ionizing radiation dosimetry (2017).

However, during the course some reference will be made to the classical Attix textbook:

- F.H. Attix: Introduction to radiological physics and radiation dosimetry (1986).

As a good supplement to the above textbook literature, we can recommend:

- M.W. Kissick and S. Fakhraei: Lectures on Radiation Dosimetry Physics: A Deeper Look into the Foundations of Clinical Protocols (2016).

Recommended supplementary materials on specific subjects:

- Software manuals for the NRC user codes for EGSnrc called FLURZnrc, DOSRZnrc, and SPRRZnrc.
- ICRU 85: Fundamental quantities and units for ionizing radiation (2011).
- ICRU 90: Key data for ionizing-radiation dosimetry: measurement standards and applications (2016).
- IAEA TRS-398: Absorbed dose determination in external beam radiotherapy: An international code of practice for dosimetry based on standards of absorbed dose to water (2000, be downloaded from the IAEA web site).
- IAEA TRS-483: Dosimetry of small static fields used in external beam radiotherapy: An international code of practice for reference and relative dose determination prepared jointly by the IAEA and AAPM (2017, can be downloaded from the IAEA web site).

- JCGM 100:2008: GUM - Guide to the expression of uncertainty in measurement (2008, can be downloaded from the BIPM web-site: <https://www.bipm.org/utis/common/documents/jcgm>).
- JCGM 200:2012: VIM - International Vocabulary of Metrology - Basic and General Concepts and Associated Terms (2012, can be downloaded from the BIPM web-site: <https://www.bipm.org/utis/common/documents/jcgm>).

## 8 Learning objectives

After this course, the student will be able to:

- define the prime quantities in medical radiation dosimetry.
- define the basic concepts in metrology (e.g. traceability and uncertainty).
- describe the interactions between radiation and matter.
- explain the theoretical basis for medical dosimetry (i.e. cavity theory).
- explain Fano's theorem.
- explain the meaning of restricted stopping power and its use in Spencer-Attix cavity theory.
- explain the basics of the TRS-398 measurement protocol for high-energy photons and electrons.
- explain the main differences between kV and MV photon dosimetry.
- solve dosimetry problems related to reference dosimetry using the TRS-398 formalism.
- identify and analyze dosimetry problems related to measurement in non-reference conditions. (e.g. measurements in the build-up zone, in small fields or in heterogeneous media).
- calculate fluence spectra and dose deposition for simple situations using the EGSnrc Monte Carlo user codes FLURZnrc and DOSRZnrc.
- explain the signal-generating mechanisms and the basis characteristics for a range of dosimetry systems such as ion chambers and solid-state detectors.
- define the dose deposition kernel of a radionuclide decaying in water.
- explain the concept of biokinetic distribution models.
- calculate organ doses from S-factors and MIRD values.

## 9 Teaching methods

- Dialog-based teaching and lectures
- Theoretical exercises
- Simple Monte Carlo calculations
- Simple demonstrations will be carried out in the lecture room and in the accelerator dosimetry laboratory (Buid. 313)

## 10 Intended audience

Hospital physicists who are still undergoing training and graduate students (physics or engineering). Some practical knowledge about medical radiation dosimetry and ion-chamber dosimetry is an advantage.

## 11 Pre-registration

Please send a mail to [clan@dtu.dk](mailto:clan@dtu.dk) any time to indicate if you are potentially interested in this course.

## 12 Registration

Go to the above web-site and download the registration form.

## 13 Cancelation and payment

DTU Nutech will inform all registered participants before May 1, if the required minimum number of participants has been reached. The course will be canceled unless enough participants register. An invoice will be sent out during May. Final registration of participants will be made in order of their payments.

Fees are refunded in full if we receive notification of a participant's cancelation at least one month before the start of the course. No refund is made for cancelations made later, or for not attending the course (no-shows). Cancelation notification must be made in writing or by fax or e-mail. Substitute participants are welcome, without prior notice, should the registrant be unable to attend the course.

DTU Nutech reserves the right to modify course material, substitute speakers without notice, or to cancel the course. If the course must be canceled (for example, as a result of illness among the main instructors), registrants will be notified as soon as is possible and they will receive a full refund of fees paid. DTU Nutech will not be responsible for discount airfare penalties or other costs incurred due to a course cancelation.

## 14 Course price

Course price is 10800 DKK (excl. VAT). Included in this price is:

- Copies of lecture presentations (paper and pdf).
- Daily lunch at Risø Campus.
- Course dinner at a restaurant in Roskilde.

Please note, that the textbook and the supplementary materials are not included in the price.

## 15 Computers

We will spend some time during the course performing Monte Carlo simulations using the EGSnrc code system from the National Research Council Canada. Specifically, we will use the NRC user codes called `FLURZnrc`, `DOSRZnrc`, and `SPRRZnrc`. The EGSnrc software can currently be downloaded here:

- <https://github.com/nrc-cnrc/EGSnrc/wiki/Installation-overview>

We will help you make the installation on your own computers on the first day of the course. When we started the course, installation was pretty easy, but since 2016, this has become less straightforward. So, if you have some time before the course, it will be great if you take a look at the installation instructions (see above web page), and it will be even better if you install it!

Note, that before you actually install the code on your computer, you need to have certain tools installed (like `c++` and Fortran compilers). There is more information on the EGSnrc web site about what to do during the install, and further guidance will be mailed to course participants before the course. There is also a google-group with additional information:

- Click here for link to EGSnrc google group

If you come with computers from hospitals, then make sure that you actually have the administrative permission to install new software. As hospitals are increasingly concerned with security, hospital computers can generally not be used for this purpose (unless special permissions are granted from an IT department or such). Sometime people therefore bring private computers for this purpose. Sometime the IT department make the installation in advance for the course participants. The computer does not have to be super fast or new to run the EGSnrc code.

Please send mail to `clan@dtu.dk` at least one week prior to the course in case you do NOT bring your own laptop or in case you do NOT use Windows as operating system.

Likewise, please also download the Notepad++ ascii editor before the course. The current address is (see under download):

- <http://notepad-plus-plus.org/>

## 16 Preparation

It will be good if you have spent some time preparing for the course by studying the main textbook or the other material given above. The main thing is to refresh how photons set electrons in motion, and how electrons subsequently deliver the dose to the medium. The definitions of fluence, kerma, cema, absorbed dose, stopping power, restricted stopping power and photon attenuation coefficients are essential. It is also essential to know about the ionization chamber. In the main textbook (FIORD, 2017), the key is to quickly go through chapter 2 and 3 (interactions), and then carefully study chapter 4 and 9 on dosimetry and chapter 12 on ionization chambers. In the 1986 Attix book, the interactions are covered in chapter 7 and 8, and the main dosimetry material is in chapter 4 and 10, while the ionization chambers are dealt with in chapter 12. If possible, see how far you can get with the installation of the EGSnrc Monte-Carlo code as described above.

## 17 Location and maps

The main lectures take place at DTU Nutech, Center for Nuclear Technologies, Technical University of Denmark, Risø Campus build. 201, Frederiksborgsvej 399, 4000 Roskilde, GIS coordinates: 55.693425, 12.085412. At least part of the course will be in our medical dosimetry laboratory in building 313. The walk from the entrance gate of the Risøe Campus to building 201 is about 13 minutes.



## 18 Public transport

Use bus 600S or 216 from Roskilde station to Risø campus. Note, that the bus stop for bus 600S is at the back side of Roskilde station (near the hospital). A tunnel at the South end of the tracks connects to the 600S bus stop. The bus stop for 216 is just outside Roskilde station (front side).

## 19 Accommodation

The course participants arrange their own accommodation. However, we may be able to recommend hotels in Roskilde or Copenhagen such as these:

- – Zleep Hotel Roskilde, Roskilde (tidl. Prindsen)
  - <https://www.zleephotels.com/da/hotel/roskilde/>
  - [roskilde@zleephotels.com](mailto:roskilde@zleephotels.com)
  - Comment: This hotel is in a walking distance from the train/bus station in Roskilde.
- – Hotel Scandic, Roskilde
  - <http://www.scandichotels.com/Hotels/Countries/Danmark/Roskilde>
  - [roskilde@scandichotels.com](mailto:roskilde@scandichotels.com)
  - Comment: This hotel is in a walking distance from the train/bus station in Roskilde.

- – Comfort hotel Vesterbro (Copenhagen)
  - <https://www.nordicchoicehotels.com/comfort/comfort-hotel-vesterbro/>
  - [info.vesterbro@choice.dk](mailto:info.vesterbro@choice.dk)
  - Comment: This hotel is in a walking distance from the central station in Copenhagen. To get to the course: Take a train to Roskilde (30 min), then a bus (600S or 216) to the course site.
- – Danhostel, Roskilde Vandrerhjem.
  - <https://www.danhostel.dk/hostel/danhostel-roskilde>
  - [roskilde@danhostel.dk](mailto:roskilde@danhostel.dk) (Phone: +45 4635 2184)
  - Comment: This hostel has a very nice location close to the viking ship museum in Roskilde, however public transport to DTU is very limited. However, if you bring a bike, you have a nice 5 km bike ride to clear up your mind.

## 20 Language

The 2019 course will be given in English. All slides and other material will be in English.

## 21 Instructors

**BL** Bent Lauritzen, DTU Nutech

**CA** Claus E. Andersen, DTU Nutech

**LL** Lars Lindvold, DTU Nutech

**MB** Mark Bailey, DTU Nutech

**MJ** Mikael Jensen, DTU Nutech

## 22 Outline of course sessions

The following provides keywords and simple statements to help outline the contents of the individual course sessions. Except for Monday, we start each day at 9:00 in the morning, and except for Friday, we will run to 16:00 or 17:00. We start mornings with a review of the activities of the previous days. We have a dinner in Roskilde on Wednesday evening.

**Monday 10:00–11:00. Welcome.** Practical information and a brief outline of the course.

- Instructor: CA.
- Presentation of DTU Nutech
- Presentation of course participants and instructors
- Hand out of course materials
- Outline of learning objectives



- Logistics

**Monday 11:00–12:00 Quantities** The purpose is to define the main quantities and units used in dosimetry.

- Instructor: CA.
- Text: FIORD chapter 4.
- Meaning of the word "Dosimetry"
- Meaning of "Quantities and units"
- Ionizing radiation (directly vs. indirectly)
- Stochastic vs. non-stochastic quantities
- Fluence
- Planar fluence
- Kerma
- Energy imparted
- Absorbed dose
- Exposure
- Linear energy transfer (LET)

**Monday 13:00–15:00 Photon interactions.** The purpose is to present the physics of photon interactions.

- Instructor: BL.
- Text: FIORD chapter 3
- Compton effect
- Photoelectric effect
- Pair production

**Monday 15:00–16:15 MC introduction.** The purpose is to present the general use of Monte Carlo calculations in dosimetry and to install the main EGSnrc user codes (DOSRZnrc and FLURZnrc) on the participant's own laptops.

- Instructors: CA.
- Text: FIORD chapter 8 and EGSnrc manuals PIRS 702 and 801.
- How does MC work?
- Use of MC in dosimetry.
- Uncertainty and limitations.
- EGSnrc interface and input parameters.
- EGSnrc output.
- Installation

---

**Tuesday 09:00–11:00. Charged particle interactions.** The purpose is to present the physics of charge-particle interactions.

- Instructor: BL.
- Text: FIORD chapter 2
- Interaction classifications (hard, soft etc.)
- Stopping power (Bethe formulation)
- Bragg curve, straggling and the CSDA
- Radiation yield and x-ray production
- Mass-stopping power, restricted mass stopping power, and range
- Electron backscattering
- Activation with particle beams
- How to get access to mass-stopping powers?

**Tuesday 11:00–12:00. Charge-particle and radiation equilibria.** The purpose is to present the concepts of charged-particle and radiation equilibria.

- Instructor: CA.
- Text: FIORD 4.8–4.12.
- Radiation equilibrium
- Charged-particle equilibrium
- Failure of CPE.
- PCPE.
- Depth-dose curves.

**Tuesday 13:00–14:00. Gas-filled detectors** Basic detector systems for dosimetry with focus on gas-filled detectors.

- Instructor: CA.
- Text: FIORD chapter 12.
- The general framework for dosimetry
- Detector materials
- Gas-filled detectors (ionization chambers)
- The principle of gas-filled detectors (gas-amplification; IC, proportional and Geiger counters).
- Free-air ion chambers for kV-dosimetry
- Thimble chambers
- Flat chambers
- Well chambers
- Charge and current measurements (incl. leakage considerations)
- Recombination physics
- The nature of  $W$  and  $\overline{W}$

**Tuesday 14:00–15:00. Cavity theory.** The purpose is to present the concepts of cavity theory.

- Instructor: CA.
- Text: FIORD chapter 9.
- The general framework for cavity dosimetry
- Bragg-Gray theory
- Spencer-Attix theory

**Tuesday 15:00–17:00. MC calculations (example).** The purpose is to perform a simple, but relevant, demonstration of computations of EGSnrc . All participants run the same computations guided by the instructors.

- Instructors: CA.
- Text: FIORD chapter 8 and EGSnrc manuals PIRS 702 and 801.
- Re-finding the basic interaction parameters from MC simulations
- Scatter calculations (lateral + longitudinal).
- Energy spectra vs. depth
- Bremsstrahlung calculation

---

**Wednesday 09:00–10:00. Radiation transport and Fano's theorem** Understanding Fano's theorem.

- Instructor: CA.
- Text: FIORD chapter 9.6.
  - Boltzmann radiation transport equation and energy conservation
  - Fano's theorem: What does it mean?
  - Fano's theorem: How to prove it?
  - Formulations of Fano's theorem.
  - Relation to interaction coefficients.
  - The slowing-down spectrum of electrons.
  - Alternative proof of BG-cavity theory.

**Wednesday 10:00–11:00. Cavity theory.** More about cavity theory as applied to ion chambers.

- Instructor: CA.
- Text: FIORD chapter 9.
  - The general framework for cavity dosimetry
  - Bragg-Gray theory
  - Spencer-Attix theory
  - Understanding the track-end terms in Spencer-Attix cavity theory
  - Burlin theory
  - Large vs. small photon detectors
  - To what extent is SA-cavity theory an approximative solution?
  - Use of EGSnrc for such computations.

**Wednesday 11:00–12:00. TRS-398 dosimetry protocols.** Code of practice for absorbed-dose-to-water measurements

- Instructor: CA.
- Text: FIORD chapter 15 and IAEA TRS-398
- The  $N_{D,w}$  formalism
- Definition of reference dosimetry
- Correction factors
- Beam quality specifications (beam quality index)
- High-energy photon dosimetry
- Effective point of measurements

**Wednesday 13:00–14:00 Electron dosimetry.** Electron dosimetry

- Instructor: MB.
- Text: FIORD 9.2.6, 9.3.2.2 and IAEA TRS-398
- Mega-voltage electron dosimetry
- Depth-dependence of stopping-power ratios
- Parallel-plate ionization chambers and the importance of guarding

**Wednesday 14:00–17:00. MC exercise** Computing with Monte Carlo. The purpose is to perform simple but relevant computations with EGSnrc-rz user codes.

- Instructor: CA.
- Text: PIRS 702 and 801.
- EGSnrc user-codes FLURZnrc and DOSRZnrc for fluence and dose computations.

**Wednesday 18:30 Course dinner** Dinner in Roskilde.

- Instructor: LL.

---

**Thursday 09:00–11:00. Internal dosimetry.** The objective is to outline the principles of internal dosimetry.

- Instructor: MJ.
- Text: FIORD chapter 18
- The basis for Olinda.

**Thursday 11:00–12:00. kV dosimetry** Introduction to kV dosimetry.

- Instructor: CA.
- Text: FIORD chapter 7.3, 9.5, 11.2 and 15.3.1.
  - Bremsstrahlung
  - X-ray spectra
  - Characteristic angle

- Primary standards (free-air chamber)

**Thursday 13:00–14:00. kV dosimetry** kV dosimetry

- Instructor: CA.
- Text: FIORD chapter 7.3, 11.2, 15.3.1 and 17.
  - kV vs. MV photon dosimetry
  - Fano's theorem: What does it mean for kV dosimetry.
  - HVL as a beam quality specifier
  - Protocols for dosimetry
  - The AAPM TG-61 protocol
  - Air kerma vs. water kerma
  - Reference dosimetry for diagnostic radiology

**Thursday 14:00–15:00. Radiation protection and solid-state detectors** Quantities in radiation protection and an introduction to solid-state detectors.

- Instructor: CA.
- Text: FIORD chapter 14
- Operational dose quantities in radiation protection: ambient dose equivalent  $H^*(d)$  and personal dose equivalent,  $H_p(d)$ .
- Pulsed vs. continuous beams (a warning).
- Solid-state detectors (scintillators, TLD/OSL/RL, diodes, diamonds etc.)

**Thursday 16:00–17:00. Neutron, proton, and micro dosimetry.** An introduction to particle therapy dosimetry, neutron interactions, and micro dosimetry.

- Instructor: CA.
- Text: FIORD chapter 2.4.11, 3.11, and 7.6.
- Track-structure theory
- Rossi chamber
- Micro-dosimetry quantities
- Ionization-density vs. LET
- Particle therap dosimetry (proton + carbon ions)
- Classification of neutrons and sources and applications of neutrons
- Neutron interactions (incl. activation)
- Principles of neutron dosimetry
- Shielding against neutrons

---

**Friday 09:00–10:00. Chemical dosimetry.** The objective is to present the basis for chemical dosimetry ("free-radical dosimetry", Fricke, change in optical properties). A brief regress to biology will also be made.

- Instructor: LL.
- Text: FIORD chapter 13

- The basics of chemical dosimeters
- The Alanine dosimeter
- Primer on radiochemistry: radical formation, G-value and radiation damage in tissue
- Fricke dosimeter: The workhorse of aqueous chemical dosimeters and other dosimeters based on colour forming radiochemical reactions
- 3D dosimeters based on radiation induced polymerisation of gels and dyed solid polymers
- Film dosimetry

**Friday 10:00–11:00. Uncertainty and traceability.** Metrology basics

- Instructor: MB.
- Text: IFORD chapter 1.7 and 11.6
- GUM and VIM and other primary sources on information.
- What is an uncertainty budget and what is it good for?
- Standard uncertainty and experimental standard deviations.
- Uncertainty evaluation (Type A + B) and communication
- Combined uncertainty. Expanded uncertainty. Coverage factor k.
- Examples of uncertainty evaluations
- Hypothesis testing with *a priori* uncertainty.
- Test if repeated measurements comply with the *a priori* uncertainty.
- Metrology introduction: Traceability. Realization of a quantity. Example: Calorimetry. Primary and secondary standards. Reference dosimetry.

**Friday 11:00–12:00. Exam.** Exam

- Instructor: CA.
- Written exam in the material covered during the course.
- The test consists of many small questions.

**Friday 13:00–14:00. Sources of ionizing radiation in medical radiation dosimetry.**

An review of radiation sources within the field of medical radiation dosimetry.

- Instructor: MJ.
- What is "medical radiation"?
- What is the "medical radiation dosimetry"?
- What are the "big" questions within the field of "medical radiation dosimetry"?
- Dosimetry in radiotherapy, diagnostics/imaging and nuclear medicine
- What about radiation protection?
- Radioactive sources and accelerators
- Beams: photons, electrons, protons etc.
- Pulsed beams vs. radioactive sources

- Scanning beams vs. broadened beams
- How is the intensity of the radiation sources characterized (mA, fluence, activity)
- Chain of events (and time scales) from primary particle production to thermalized secondary electrons including chemical/biological "side effects"

**Friday 14:00–14:30 Closure** Evaluation, certificates, and course closure.

- Instructor: CA.
- Course review and highlights