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. and supplementary material. The key elements in the course are:

- Interaction between radiation and matter
- Monte Carlo calculation of radiation transport
- Cavity theory
- Radiation detection techniques
- Protocols for high-energy x-ray and electron dosimetry with ion chambers
- Proton dosimetry physics
- Metrology (traceability and uncertainty)

The course will be presented by researchers from DTU Nutech (Center for Nuclear Technologies, Technical University of Denmark, Risø Campus, Roskilde, Denmark). The 2018 course will be given in English and international participants are welcome.

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1 Disclaimer

This is an outline of the course. In the 2018, the course will include an emphasis on dosimetry in proton beams and certain lectures will be removed or reduced. These changes have not yet been implemented in this document or the scheme. Additional adjustments 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/Radiation_physics/Projects/Medical-dosimetry/medical_radiation_dosimetry_course

For the electronic version of this document, you can also [CLICK HERE]. Alternatively, go to the main DTU web-site (www.dtu.dk) and navigate to the site for the center: "DTU Nutech".
3 Course title

- Medical radiation dosimetry course

4 Course dates

- June 18–June 22, 2018

5 Number of participants

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

6 Deadlines

- May 1, 2018: Registration deadline.

7 Course textbook and materials

The course will be based on the following texts:

- TRS398: Absorbed dose determination in external beam radiotherapy (can be downloaded from the IAEA web site).
- TRS483: 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 (can be downloaded from the IAEA web site).
- NIST Technical Note 1297: Guidelines for evaluating and expressing the uncertainty of NIST measurement results (1994) (can be downloaded from the NIST web site).
- Software: The NRC user codes for EGSnrc called FLURZnrc, DOSRZnrc, and SPARRZnrc.
The new book by Andreo et al. (2017) has replaced the original textbook by Attix (1986) as the main text in the course.

Recommended supplementary literature:


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 measurements in standard conditions using the TRS-398 formalism.
- identify and analyze dosimetry problems related to measurement in non-standard 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, DOSRZnrc, and SPRRZnrc.
- 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
- Theoretical exercises
- Simple Monte Carlo calculations
- Simple demonstrations of equipment will be carried out 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 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 15, 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 ”Introduction to radiology physics and radiation dosimetry” by F.H. Attix. is not included in the price.

15 Computers

The NRC user codes FLURZnrc, DOSRZnrc, and SPRRZnrc for the Monte Carlo program EGSnrc will be used by the participants. It is therefore strongly recommended that the participants bring their own laptops to the course (running Microsoft Windows or Linux). The Monte Carlo code will be installed on their computers during the course.

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.

Before the course, it would be useful if the participants register and download the EGSnrc software. The current address is:


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

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

16 Preparation

As preparation for the course, it is strongly recommended that the participants study the following chapters in the textbook by Attix (approximately 85 pages): Chapter 1, 2, 4, and 10.

If possible, download the EGSnrc and the nodepad++ software, as detailed in the previous section.

17 What about a practical course in dosimetry?

A new course is under development at DTU Nutech. This is the ”Accelerator Dosimetry Course”. This course includes practical exercises and demonstrations. Please check the web site for further information or indicate your potential interest with a mail to clan@dtu.dk.
18 Location and maps

DTU Nutech, Center for Nuclear Technologies, Technical University of Denmark, Risø Campus build. 201, Frederiksborgsvej 399, 4000 Roskilde, Phone (+45) 4677 4912. GIS coordinates: 55.693425, 12.085412.

At least part of the course will be in our new facilities in Build 313.

19 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).

20 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)
  - roskilde@zleephotels.com
  - Comment: This hotel is in a walking distance from the train/bus station in Roskilde.

- Hotel Scandic, Roskilde
  - 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-vesterobro/
  • 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.

21 Language
The 2018 course will be given in English. All slides and other material will be in English. The course may be given in Danish at a later time.

22 Instructors
AM Arne Miller, DTU Nutech
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

23 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 every morning at 9:00 with a review of the previous day’s sessions.

Monday 10:00–10:30. Welcome. Practical information and a brief outline of the course.
  • Instructor: CA.
  • Hand out of course materials
  • Outline of learning objectives
  • Logistics

Monday 10:30–12:00 Quantities The purpose is to define the main quantities and units used in dosimetry.
  • Instructor: CA.
  • Text: Attix chapter 1 and 2, ICRU 85, and NIST 1297.
  • Meaning of the word “Dosimetry”
  • Meaning of "Quantities and units”
  • Ionizing radiation (directly vs. indirectly)
Medical Radiation Dosimetry Course

- Stochastic vs. non-stochastic quantities
- 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: Attix chapter 7.
- Compton effect
- Photoelectric effect
- Pair production
- Other actions incl. photonuclear
- How to get access to these cross-sections?
- Effective atomic number

**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: PIRS 702 and 801.
- How does MC work?
- Use of MC in dosimetry.
- Uncertainty and limitations.
- EGSnrc interface and input parameters.
- EGSnrc output.
- Installation

**Monday 16:15–17:00. Sources of ionizing radiation in medical radiation dosimetry.**
An outline 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
Medical Radiation Dosimetry Course

- 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"

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

- Instructor: BL.
- Text: Attix chapter 8 and 9.
- 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.
- Radiation equilibrium
- Charged-particle equilibrium
- Failure of CPE.
- TCPE.
- Depth-dose curves.

**Tuesday 13:00–14:00. Cavity theory.** The purpose is to present the concepts of cavity theory.

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

**Tuesday 14:00–15:00. Gas-filled detectors** Basic detector systems for dosimetry with focus on gas-filled detectors.

- Instructor: CA.
- 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 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: PIRS 702 and 801.
- Re-finding the basic interaction parameters from MC simulations
- Scatter calculations (lateral + longitudinal).
- Energy spectra vs. depth
- Bremsstrahlung calculation

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

- Instructor: LL.

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

- Instructor: CA.
  - 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 10:00–12:00. Cavity theory.** More about cavity theory as applied to ion chambers.

* Instructors: CA.
* Text: Attix chapter 10.
  – The general framework for cavity dosimetry
  – Bragg-Gray theory
  – Spencer-Attix 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 13:00–14:00 Metrology** Traceability, calibrations and primary standards.

* Instructors: MB.
* Text: Attix chapter 1 and 2, ICRU 85, and NIST 1297.

**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 (including SPRZnrc).

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

**Thursday 09:00–10:00. kV dosimetry** Using cavity theory and Fano’s theorem for kV dosimetry.

* Instructors: CA.
* Text: Attix chapter 3 + 12.
  – kV vs. MV photon dosimetry
  – Fano’s theorem: What does it mean for kV dosimetry.
  – HVL as a beam quality specifier
  – Protocols for dosimetry
  – AAPM TG-61 (air kerma based)
  – Primary standards (free-air chamber)

**Thursday 10:00–12:00. Internal dosimetry.** The objective is to outline the principles of internal dosimetry.
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- Instructor: MJ.
- Text: Suppl. material.

Thursday 13:00–14:00. Dosimetry protocols. Code of practice for absorbed-dose-to-water measurements
- Instructor: CA.
- The $N_{D,w}$ formalism
- High-energy photon dosimetry
- High-energy electron dosimetry
- Differences between diodes and ionization chambers
- Effective depth of measurements

Thursday 14:00–15:00. SP-ratio calculations. Computing mass-stopping power ratios with Monte-Carlo.
- Instructor: CA.
- User-code SPRRZnc.

Thursday 15:00–16:00. 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: Attix chapter 14, sec. II+III
- 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 dye-doped solid polymers

Friday 09:00–10:00. Uncertainty budgets. Uncertainty budgets.
- Instructor: AM.
- Text: NIST-1297 and TRS398.
- 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.

**Friday 10:00–11:00. Neutron, proton, and micro dosimetry.** An introduction to particle therapy dosimetry, neutron interactions, and micro dosimetry.

- Instructor: CA.
- Text: Attix chapter 16(VIII).
- Track-structure theory
- Rossi chamber
- Micro-dosimetry quantities
- Ionization-density vs. LET
- Particle therapy 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 11:00–12:00. Radiation protection and solid-state detectors** Quantities in radiation protection and an introduction to solid-state detectors.

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

**Friday 13:00–14:00 General dosimeter characteristics and review of course.** An outline of the fundamental characteristics of dosimetry systems.

- Instructor: CA.
- Text: Attix chapter 11.
- Dose response (linearity, supralinearity, sub-linear etc.)
- Energy response (incl. measurements in build-up region)
- LET response
- Dose-rate response
- Angular response
- Time resolution
- Spatial resolution
- Fading
- Reproducibility
- Detection limit
- Course review and highlights

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