UMM UNIVERSITÄTSMEDIZIN MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

Module Handbook

Heidelberg University
Medical Faculty Mannheim

Master of Science "Biomedical Engineering"

Period of Study: Four semester full time; yearly intake (winter term)

Type of Study: consecutive; research oriented

Start: Sept. 2010/2011

Areas of Study:

- Radiotherapy
- Medical Imaging
- Computational Medical physics

Location: Medical Faculty Mannheim / UMM; Heidelberg University

ECTS-credits: 120

Language of instruction: English

Target Group:

- Physics (B.Sc. or higher)
- Engineering (with basic knowledge in physics and computer science)
- Mathematics and computer science (with basic knowledge in physics)

Latest revision: October 13, 2020

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1. Quality Objectives and Overview

1.1 Preamble: Qualification objectives at Heidelberg University

In accordance with its mission statement and constitution, Heidelberg University's degree courses have subject-related, transdisciplinary and occupational objectives. They aim to provide a comprehensive academic education equipping graduates for the world of work.

The main points of the competence profile are the following:

- developing subject-related skills with a pronounced research orientation
- developing the ability to engage in transdisciplinary dialogue
- developing practice-related problem-solving skills
- developing personal and social skills
- promoting the willingness to assume social responsibility on the basis of the skills acquired

1.2 Qualification objectives of the Master of Science program in Biomedical Engineering

1.2.1 Individual qualifications

The program aims at enabling students to work and/or carry out independent research in the field of medical physics.

After completing this course, students

- will have acquired basic knowledge of anatomy, physiology, genetics and also basic knowledge of biophysics and engineering mathematics (numerically oriented), including programming
- will have learned and thus be able to translate and apply this knowledge into daily practice, independently of the specialization

Students completing elective courses

- will have acquired a broad knowledge of radiotherapy and radiotherapy techniques, computational physics, medical imaging, or optics
- tackled successfully all technical issues arising in these fields that are related to Medical Physics
- are able to analyse and evaluate recent technological developments and advances in the field
- will also be able to independently tackle current challenges and to find solutions or establish new areas of research.

1.2.2 Interdisciplinary qualifications

Based on knowledge acquired in specialized lab projects / research projects, students will

- have acquired all traits to understand scientific working and thinking
- easily communicate and write in (foreign) specialized scientific language
- be able to critically assess, and evaluate medical science.

Students will not only learn how to present and discuss data in scientific meetings but will also be able to describe technical issues in layman's terms (e.g. when they will have to communicate with patients). They will have all traits necessary to take responsibilities for their field and to constitute, lead and motivate expert teams. The students will also be trained to independently develop new ideas and to autonomously develop their own area of research. Ultimately, all students completing this course will be able to advance the socio-economic state of their academic and non-academic environment.

2. Possible career options

Graduates' career prospects are best in health-care/life-science sectors, research organizations and the medical technology industry (producers of biomedical instruments/imaging systems, health-care-oriented software companies, the pharmaceutical industry, etc.). Successful completion of the course may also qualify graduates for further certification as a state radiation-protection commissioner (depending on the respective country). In Germany, for example, the status of a certified medical physics expert can be attained after two additional years of supervised practical work in a qualified department and an additional examination specified in the German Radiation Protection Ordinance.

3. General requirements of the study

3.1 Students profile

The Master of Science (M.Sc.) program in Biomedical Engineering is an interdisciplinary course open for candidates with undergraduate or higher education in:

- Physics (Bachelor of Science or higher)
- Engineering (with basic knowledge in physics and computer science)
- Mathematics and computer science (with basic knowledge in physics)

This program is science oriented. In particular, the program is intended for those students planning to work in the medical field (either as medical physics expert after extra qualification in research or in instruments/software-health-orientated companies). In this respect, the courses provide theoretical background and practical elements where the knowledge can be applied using modern clinical equipment.

Also this programme has a strong bias towards computational science. This reflects the ever-increasing demand for IT competence in this field, in conjunction with knowledge of biomedical devices and their usage.

Graduates from this program are well prepared for positions in hospitals, academia and industry.

3.2 Courses locations

The master courses are located mostly at Mannheim Medical Campus. However some courses are located at Heidelberg University Campus in Heidelberg.

3.3 Course material

The learning material of all courses is accessible at the learning platform Moodle of the Medical Faculty Mannheim. The access to the platform is enabled for the students enrolled in the M.Sc. program. Over this platform all administrative documents for students are managed as well, including the lecture schedule, the rules and regulations, the course selection and registration, and the grades reports.

https://moodle.umm.uni-heidelberg.de/moodle/

3.4 Master thesis

The M.Sc. program in Biomedical Engineering is nationally and internationally connected to leading institutions in research and education for radiotherapy and medical imaging.
The master thesis can be conducted in any of the internal research groups at the University Medical Center Mannheim or by any of the cooperation partners in a topic related to medical physics. The option to perform the master thesis in an external institution is possible provided that all the requirements stipulated by the Academic Committee are fulfilled. More information about this topic is found in the guideline available in Moodle.

3.5 Joint degree with Shanghai Jiao Tong University, China

The M.Sc. in Biomedical Engineering offers to students the possibility of a double degree through the exchange program with Shanghai Jiao Tong University in China. The contents of the programme cover all aspects of the innovative field of computational bio-photonics, i.e. all aspects of the diagnostic and therapeutic use of photons in medicine supported by advanced computing.

Students who decided to participate in the joint degree should stay in Mannheim during the first year of studies. The second year gives two options:

- Option 1 is to carry out the 3rd and 4th semester (elective taught modules or Master thesis, respectively) in Shanghai.
- Option 2 is to only perform the 3rd semester (elective taught modules) in Shanghai and complete the Master Thesis in Mannheim/Heidelberg.

To receive a joint degree diploma, students have to be at least half a year in any of both institutions.

4. Specializations included in the program

The following specializations are available in the program.

(I) Module M3: Radiotherapy (16 ECTS[1])

The specialization in Radiotherapy is focused on basic and advanced knowledge related to advanced radiation planning and treatment methods (3D, IMRT, VMAT, IORT, IGRT)

[1] European Credit Transfer System. 1 ECTS is equivalent to 30 study hours.

of cancer in radiation therapy, to radiotherapy equipment (LINAC, CT, MRI, PET, IORT systems), to give basic insight for clinical tasks as well as for advanced research work.

(II) Module M4: Medical Imaging (34 ECTS)

Medical Imaging specialization is focused on oncological radiotherapy treatment planning and monitoring by using physiological and functional imaging of CT, MRI and PET. The courses are oriented to provide the student with fundamental knowledge in processing, analysis and quantification of medical images. Special attention is laid on the interdisciplinary approach to radiotherapeutic cancer treatment.

(III) Module M5: Computational Medical Physics (37 ECTS)

Computational Medical Physics is focused on the fields of mathematics, computer engineering, computer science and physics. The aim of the advanced modules in this specialization is the knowledge in modern computational physics with application in life sciences. The courses are focused on inverse problems for image reconstruction, restoration, analysis, simulation, modelling and instrumentation.

5 Curriculum

General Timetable:

<table>
<tr><th>1st Semester</th><th>2nd Semester</th><th colspan="2">3rd Semester</th><th colspan="2">4th Semester</th></tr>
<tr>
<td>Taught Modules/ Workshops:

• M1 module
• M2 module
• M3 module
• M4 module
• M5 module

(min. 30 ECTS)</td>
<td>Taught Modules/ Labs/ Seminars:

• M2 module
• M3 module
• M4 module
• M5 module
• M6 module

(min. 30 ECTS)</td>
<td colspan="2">Taught Modules/ Labs/ Seminars:

• M3 module
• M4 module
• M5 module
• M7 module

(min. 30 ECTS)</td>
<td colspan="2">M8 Master Thesis

(30 ECTS)</td>
</tr>
<tr>
<td>Specializations:

• Radiotherapy
• Medical Imaging
• Computational Medical Physics</td>
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• Medical Imaging
• Computational Medical Physics</td>
<td>Specializations:

• Radiotherapy
• Medical Imaging
• Computational Medical Physics</td>
<td>Specializations:

• Neurosciences
• Medical Imaging/ Biomedical Optics
• Computer Engineering</td>
<td>Specializations:

• Radiotherapy
• Medical Imaging
• Computational Medical Physics</td>
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• Computer Engineering</td>
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<tr>
<td>Venue:

Medical Faculty Mannheim Heidelberg University, Germany</td>
<td>Venue:

Medical Faculty Mannheim Heidelberg University, Germany</td>
<td>Venue:

Medical Faculty Mannheim Heidelberg University, Germany</td>
<td>Venue:

Shanghai Jiao Tong University, Shanghai, China</td>
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</table>

Modules Overview:

1st Semester Winter Term (Mannheim/ Heidelberg)	Module	Course Number	Course Name	ECTS	Type of course
	M1 Advanced Physics and Mathematics for Medical Applications	1.1	Biophysics	1.0.	Mandatory
		1.2	Engineering Mathematics + Exercises	3.0	Mandatory
	M2 Medicine and Radiobiology	2.1	Basic Molecular and Cellular Biology	1.0	Mandatory
		2.2	Basic Medical Science	2.0	Mandatory
		2.3	Radiobiology	2.0	Mandatory
		2.4	Basic Cellular Biology/Radiobiology Lab	1.0	Mandatory
	M3 Radiotherapy	3.1	Radiation Physics and Instrumentation	2.0	Mandatory
		3.2	Radiation Protection	1.0	Mandatory
		3.3	Radiotherapy Treatment Planning/Quality Assurance	2.0	Mandatory
		3.4	Treatment Planning and Quality Assurance Lab	1.0	Elective
		3.5	Image Guided Radiotherapy	1.0	Elective
		3.6	Special Radiotherapy Techniques	2.0	Elective
	M4 Medical Imaging	4.1	Physics of Imaging Systems	2.0	Mandatory
		4.2	Biomedical Optics	1.0	Mandatory
		4.3	Biomedical Engineering	2.0	Mandatory
		4.4	Basic Optics and Laser	1.0	Elective
		4.5	MR-Radiology Lab	1.0	Elective
		4.7	Nuclear Medicine + Exercises	4.0	Mandatory
	M5 Computational Medical Physics	5.1	Image Analysis + Exercises	4.0	Mandatory
		5.2	Matlab Programming	4.0	Elective

2nd Semester Summer Term (Mannheim/ Heidelberg)	Module	Course Number	Course Name	ECTS	Type of course
	M2 Medicine and Radiobiology	2.5	Seminar Radiobiology	1.0	Elective
	M3 Radiotherapy	3.7	Lab Medical Physics in Radiotherapy	5.0	Elective
		3.8	Seminar: Radiotherapy Techniques	2.0	Elective
	M4 Medical Imaging	4.6	Seminar: MR Methods and Technology	2.0	Elective
		4.8	Lab Medical Physics in Imaging	5.0	Elective
		4.9	Seminar: Physics of Advanced MRI/CT Techniques	6.0	Elective
		4.11	Medical Devices and Imaging Systems	4.0	Elective
	M5 Computational Medical Physics	5.3	Simulators in Games and Medicine + Exercises	8.0	Elective
		5.4	Volume Visualization + Exercises	8.0	Elective
		5.5	Inverse Problems + Exercises	8.0	Elective
		5.6	Computational Medical Physics Lab	5.0	Elective
	M6 Abroad Course	6.1	Shanghai Workshop	1.0	Elective

3rd Semester Winter Term (Mannheim/ Heidelberg)	Module	Course Number	Course Name	ECTS	Type of course
	M3 Radiotherapy	3.4	Treatment Planning and Quality Assurance Lab	1.0	Elective
		3.5	Image Guided Radiotherapy	1.0	Elective
		3.6	Special Radiotherapy Techniques	2.0	Elective
	M4 Medical Imaging	4.2	Biomedical Optics	1.0	Mandatory
		4.3	Biomedical Engineering	2.0	Mandatory
		4.6	Seminar: MR Methods and Technology	2.0	Elective
		4.7	Nuclear Medicine + Exercises	4.0	Mandatory
		4.10	Advanced Imaging Techniques	2.0	Mandatory
		4.11	Medical Devices and Imaging Systems	4.0	Elective
		4.12	MRT Basics	2.0	Elective
		4.13	X-Ray Diagnostics and Sonography	2.0	Elective
	M5 Computational Medical Physics	5.1	Image Analysis + Exercises	4.0	Mandatory
		5.2	Matlab	4.0	Elective
	M7 Master Thesis Preparation	7.1	General Science Skills	3.0	Mandatory
		7.2	Specialized Lab Project	16.0	Mandatory

	Neurosciences	Imaging/ Biomedical Optics	Computer Engineering
3rd Semester (Shanghai)	**Elective modules (max. 30 ECTS)**	**Elective modules (max. 30 ECTS)**	**Elective modules (max. 30 ECTS)**
	• Nanotechnology (3.0) • BioMEMS (3.0) • Biomaterials (3.0) • Neurobiology (3.0) • Structure & Function of Biomacromolecules (4.5) • Theoretical Neurosciences (4.5) • Experiments of modern lab animal science (1.5) • Bioheat & Mass Transfer (4.5) • Neuroinformatics (3.0)	• Physical therapy technology (4.5) • Biomedical ultrasound (4.5) • Medical imaging (3.75) • New Technology in Medical Imaging (3.0) • Biomedical Sensors (4.5) • Laser medicine & biophotonics (3.0) • Frontier problems of optics (4.5) • Non-linear optics of optical fibers (4.5) • Modern optics (4.5) • Optoelectronics (3.0) • Semiconductor devices (3.0) • Processing of optical information (3.0) • Principle & technology of laser (4.5) • Non-linear optics (4.5) • Engineering optics (4.5)	• Application of Computers in Life Sciences (3.0) • Signal processing (4.5) • Digital signal processing (3.0) • Bioinformatics (3.0) • 3D image processing & volume visualization (3.0) • Adaptive filtration (3.0) • Biomedical image processing (4.5) • TMS320 digital signal processor (3.75) • Random signal processing (4.5) • Opt. estimation theory & system identification (4.5) • Computer graphics (4.5) • Wireless communication & sensor networks (3.0) • Mobile & wireless networking (4.5)

4th Semester Summer Term (Mannheim/ Heidelberg or Shanghai)	Module	Course Number	Course Name	ECTS	Type of Course
	M8	8.1	Master Thesis	30.0	Mandatory

6. Overview of the Courses

Module	Part	Course No.	Title	ECTS
M1[i]	Advanced Physics and Mathematics for Medical Applications	1.1	Biophysics	1.0
		1.2	Engineering Mathematics + Exercises	3.0
M2	Medicine and Radiobiology	2.1	Basic Molecular and Cellular Biology	1.0
		2.2	Basic Medical Science	2.0
		2.3	Radiobiology	2.0
		2.4	Basic Cellular Biology/Radiobiology Lab	1.0
		2.5	Seminar Radiobiology	1.0
M3	Radiotherapy	3.1	Radiation Physics and Instrumentation	2.0
		3.2	Radiation Protection	1.0
		3.3	Radiotherapy Treatment Planning/ Quality Assurance	2.0
		3.4	Treatment Planning and Quality Assurance Lab	1.0
		3.5	Image Guided Radiotherapy	1.0
		3.6	Special Radiotherapy Techniques	2.0
		3.7	Lab Medical Physics in Radiotherapy	5.0
		3.8	Seminar Radiation Therapy Techniques	2.0
M4	Medical Imaging	4.1	Physics of Imaging Systems	2.0
		4.2	Biomedical Optics	1.0
		4.3	Biomedical Engineering	2.0
		4.4	Basic Optics and Laser	1.0
		4.5	MR – Radiology Lab	1.0
		4.6	Seminar MR Methods and Technology: Journal Club + Presentation	2.0
		4.7	Nuclear Medicine + Exercises	4.0
		4.8	Lab Medical Physics in Imaging	5.0
		4.9	Seminar: Physics of Advanced MRI / CT Techniques	6.0
		4.10	Advanced Imaging Techniques	2.0
		4.11	Medical Devices and Imaging Systems	4.0
		4.12	MRT Basics	2.0
		4.13	X-Ray Diagnostics and Sonography	2.0

M5	Computational Medical Physics	5.1	Image Analysis + Exercises	4.0
		5.2	Matlab Programming	4.0
		5.3	Simulators in Games and Medicine + Exercises	8.0
		5.4	Volume Visualization + Exercises	8.0
		5.5	Inverse Problems + Exercises	8.0
		5.6	Computational Medical Physics Lab	5.0
M6[ii]	Abroad Course	6.1	Shanghai Workshop	1.0
M7	Master Thesis Preparation	7.1	General Science Skills	3.0
		7.2	Specialized Lab Project	16.0
M8	Master thesis	8.1	Masters project and thesis writing; Public presentation of the thesis and final examination	30.0

[i] The courses in module 1 make up a stand-alone unit with less than 5 ECTS that cannot be sensibly integrated into (an) other module(s).

[ii] The course in module 6 makes up a stand-alone unit with less than 5 ECTS that cannot be sensibly integrated into another module. In addition, it readily offers the students a short-term option for studying abroad.

7. Modules in Detail

Module 1. Advanced Physics and Mathematics for Medical Applications

Course Title	Biophysics		
Course no.	1.1	Exam Regulations	45 min exam (written/ oral/ exercises/ report): Basics in Physics.
Credit Points	1.0	Formalities or Requirements for Participation	none
Workload	30 h	Max. Number of Participants	40
Type of Course	Lecture (mandatory)	Coordinator/ Lecturer	Prof. Dr. J. W. Hesser
Turn	Yearly	Term	Winter
Language	English	Duration	Block Course
Contents of Course:	• Biophysics of DNA/sequencing, Protein/Protein structure determination and prediction.		
Learning Objectives	After completing this course the students are able to: • read and understand papers in this field in order to repeat the experiment or apply it in new fields, • apply the knowledge to concrete applications, • solve typical questions in this field of biophysical processes, • develop programs for sequence alignment, protein structure, classification, and prediction, find native conformations using force-fields.		
Course Parts and Teaching Methods	Lecture		
Useful /Required Previous Knowledge	none		
Recommended Literature	Will be given at the beginning of the lecture.		

Course Title	Engineering Mathematics		
Course no.	1.2	**Exam Regulations**	75 min exam (written/ oral/ exercises/ report): basics in physics.
Credit Points	3.0	**Formalities or Requirements for Participation**	no
Workload	90 h	**Max. Number of Participants**	40
Type of Course	Lecture (mandatory)	**Coordinator/ Lecturer**	Prof. Dr. J. W. Hesser
Turn	Yearly	**Term**	Winter
Language	English	**Duration**	Block course
Contents of Course:	• System modelling and description (numerical methods for solution of linear systems, approximation/integration, solving differential equations, optimization, Fourier transforms, and systems theory). • Matlab exercises (basic programming).		
Learning Objectives	After completing this course the students are able to: • solve typical numerical problems in computational physics, • program the solutions and use the preexisting Matlab functions for this purpose, • select the most appropriate techniques and to perform simple mathematical proofs.		
Course Parts and Teaching Methods	Lecture and practical part.		
Useful /Required Previous Knowledge	none		
Recommended Literature	Will be given at the beginning of the lecture.		

Module 2. Basic Molecular and Cellular Biology

Course Title	Basic Molecular and Cellular Biology		
Course no.	2.1	**Exam Regulations**	45 min written exam.
Credit Points	1.0	**Formalities or Requirements for Participation**	no
Workload	30 h	**Max. Number of Participants**	40
Type of Course	Lecture (mandatory)	**Coordinator/ Lecturer**	Prof. Dr. M.R. Veldwijk, Prof. Dr. P. Maier
Turn	Yearly	**Term**	Winter
Language	English	**Duration**	Block course
Contents of Course:	• Replication, transcription, translation and post-translational modification: From DNA to a functional protein. • The cell and its organelles. • Cell division, cell cycle and cell death. • Mendelian genetics and genetic diseases. • Molecular biological assays and techniques.		
Learning Objectives	This course conveys the biological background for the master program. After its completion, the students are able to: • describe the basic principles of classical genetics (Mendelian Laws), molecular genetics (from DNA to protein) and of the structure and function of cells, • explain the theory of cloning, PCR and sequencing.		
Course Parts and Teaching Methods	Lecture		
Useful /Required Previous Knowledge	none		
Recommended Literature	Will be given at the beginning of the lecture.		

Course Title	Basic Medical Sciences		
Course no.	2.2	Exam Regulations	90 min. written exam.
Credit Points	2.0	Formalities or Requirements for Participation	no
Workload	60 h	Max. Number of Participants	40
Type of Course	Lecture (mandatory)	Coordinator/ Lecturer	Prof. Dr. U. Böcker, Prof. Dr. J. Maurer, Dr. Carr
Turn	Yearly	Term	Winter
Language	English	Duration	Block course
Contents of Course:	• Medical terminology. • Macroscopic anatomy of the human body as required for physicists (anatomical relations, organ motion, differences in tissue properties and their consequences). • Focus on anatomical relations of truncus and CNS. • Overview of the physiology of cells and membranes, muscle and senses, heart and circulation, respiration and metabolism, kidney and homeostasis. • Modelling of physiology and Basic immunology. • Conceptual basic knowledge in the structure of the cell and tissues, • Continued with the Single functional portions of the macroscopic and microscopic anatomy, i.e. The digestive system, the respiratory system, • The genitourinary system, reproductive systems, and endocrine system, and Nervous system.		
Learning Objectives	After successfully completing the physiology section the students are able to: • recognize and describe the underlying regulatory roles and functional mechanisms of whole organs, • join those organ specific functions into larger regulatory circuits and construct math. models in order to simulate and predict physiological functions in healthy and pathological conditions, • understand and describe the key components of the immune system, their functions and interactions between them during an immune reaction.		
Course Parts and Teaching Methods	Physiology: plenary lectures including seminar-like discussion. Immunology: lectures. Anatomy. Lecture and practical sessions.		
Useful /Required Previous Knowledge	none		
Recommended Literature	Netter’s Anatomy, Thieme Verlag. “Physiology”, Costanzo, Saunders/Elsevier. “Human Physiology”, Silversthorn, Pearson.		

Course Title	**Radiobiology**		
Course no.	2.3	**Exam Regulations**	Presentation/ 75 min written exam/ Report
Credit Points	2.0	**Formalities or Requirements for Participation**	Successful attendance in courses , 2.1 and 2.2
Workload	60 h	**Max. Number of Participants**	40
Type of Course	Lecture /Workshop (mandatory)	**Coordinator/ Lecturer**	PD Dr. C. Herskind, Prof. Dr. M. R. Veldwijk
Turn	Yearly	**Term**	Winter
Language	English	**Duration**	Block course
Contents of Course:	• Basics of biological radiation effect (physical interaction of different radiation qualities with matter, chemical reactions, biological consequences). • DNA damage and repair; Cell cycle regulation, proliferation, signal transduction, Radiation sensitivity of cells and tissues, and its modulation. • Clinical radiobiology of tumours and normal tissue • Biological effects of dose rate, fractionation, overall treatment time, volume.		
Learning Objectives	After completing this course the students are able to: • describe the physical, chemical, and biochemical processes leading to biological radiation effects, • explain the biological basis of the effect of radiotherapy on tumours and normal tissue, and the strategies for modulating the therapeutic window, • calculate dose-modifying factors, fit mathematical models of dose-response relationships for cell inactivation, tumour control, normal-tissue complication, and volume effects, • calculate isoeffective changes in fractionation, and time factors.		
Course Parts and Teaching Methods	Lecture and practical part including presentation and exercises		
Useful /Required Previous Knowledge	Good knowledge of nuclear physics and radiation physics. Basic knowledge of chemistry, cell and molecular biology, and oncological concepts		
Recommended Literature	Hall, E. J. and Giaccia, A. J. "Radiobiology for the Radiologist" 7th Edition. Lippincott Williams & Wilkins (Philadelphia) 2012. ISBN-13: 978-1-60831-193-4 Joiner, M. and van der Kogel A. (Eds) "Basic Clinical Radiobiology" 4th Edition. Hodder Arnold (London) 2009. ISBN: 978 0 340 929 667		

Course Title	**Basic Cellular Biology /Radiobiology Lab**		
Course no.	2.4	**Exam Regulations**	Data evaluation, presentation, report.
Credit Points	1.0	**Formalities or Requirements for Participation**	Successful attendance in course 2.3.
Workload	30 h	**Max. Number of Participants**	40
Type of Course	Practical course/ Lab (mandatory)	**Coordinator/ Lecturer**	PD Dr. C. Herskind, Prof. Dr. M. R. Veldwijk, Prof. Dr. P. Maier
Turn	Yearly	**Term**	Winter
Language	English	**Duration**	Block Course
Contents of Course:	• Basics of cell culture. • Techniques in micro-biology. • Basics of molecular biology techniques (Flowcytometry, PCR, plasmid purification and restriction enzyme digest).		
Learning Objectives	After completing this course the students are able to: • use different kinds of laboratory tools and equipment, • work with cell cultures under sterile conditions, • perform molecular biology techniques such as restriction digests, PCR, and agarose gel electrophoresis, • perform the necessary calculations of concentrations and dilutions, • explain the principles of cellular radiosensitivity assays, • evaluate and interpret cell-cycle analyses by flow cytometry.		
Course Parts and Teaching Methods	Practical sessions and presentation		
Useful /Required Previous Knowledge	Basics in Biology and Chemistry		
Recommended Literature	Hall, E. J. and Giaccia, A. J. "Radiobiology for the Radiologist" 7th Edition. Lippincott Williams & Wilkins (Philadelphia) 2012. ISBN-13: 978-1-60831-193-4 Joiner, M. and van der Kogel A. (Eds) "Basic Clinical Radiobiology" 4th Edition. Hodder Arnold (London) 2009. ISBN: 978 0 340 929 667		

Course Title	Seminar Radiobiology		
Course no.	2.5	**Exam Regulations**	Min. 5 times presence in seminar, presentation
Credit Points	1.0	**Formalities or Requirements for Participation**	Successful attendance in courses 2.3
Workload	30 h	**Max. Number of Participants**	12
Type of Course	Seminar (elective)	**Coordinator/ Lecturer**	PD Dr. C. Herskind, Prof. Dr. M.R. Veldwijk
Turn	Yearly	**Term**	Summer
Language	English	**Duration**	Block course
Contents of Course:	The topic depends on the current state of the art.		
Learning Objectives	After completing this course the students are able to: • perform a literature search and read, understand, summarize, and present, a scientific paper, • follow a scientific oral presentation, take part in scientific discussions, and formulate critical questions based on hypotheses related to the current state of the art.		
Course Parts and Teaching Methods	Workflow: • Attendance in the Journal Club Radiobiology (min. 5 times) • Presentation in Journal Club (1 time) • Report submission		
Useful /Required Previous Knowledge	Basic knowledge of chemistry, cell and molecular biology, and oncological concepts.		
Recommended Literature	Will be given at the beginning of the course.		

Module 3. Radiotherapy

Course Title	Radiation Physics and Instrumentation		
Course no.	3.1	**Exam Regulations**	90 min written exam
Credit Points	2.0	**Formalities or Requirements for Participation**	none
Workload	60 h	**Max. Number of Participants**	40
Type of Course	Lecture (mandatory)	**Coordinator/ Lecturer**	Dr. Y. Abo-Madyan, Dr. S. Clausen, Dr. J Fleckenstein, Dr. M. Polednik, V.Steil, Dr. F. Stieler
Turn	Yearly	**Term**	Winter
Language	English	**Duration**	Block Course
Contents of Course:	• Foundations of radiotherapy • Medical Foundations of radiotherapy • Basic radiation physics • Dosimetric quantities and units • Radiation dosimeters and Monitoring • Basic of Linear Accelerators (Linac) • Physical aspects of photon beams		
Learning Objectives	After completing this course the students are able to: • describe the basics of radiation oncology, and medical indications and apply this knowledge using their physics background, • understand, describe and explain principles of radiation physics, dose curves for different types of radiation the radiotherapy chain and aspects which have to be considered for a successful treatment.		
Course Parts and Teaching Methods	Lecture on basic of radiation physics and radiotherapy equipment. Practical sessions. Introduction to Radiotherapy Department, Linac commissioning and treatment planning systems.		
Useful /Required Previous Knowledge	General Knowledge in Physics and Mathematics.		
Recommended Literature	Course book: Radiation Oncology Physics: a Handbook for teachers and students. E.B. Podgorsak. 2005. http://www-pub.iaea.org/mtcd/publications/pdf/pub1196_web.pdf complementary bibliography: A century in Radiology: http://www.xray.hmc.psu.edu/rci/ Radiotherapy Physics: in Practice, Williams/Thwaites, Oxford University Press, 2000. The Physics of Radiation Therapy, Faiz M. Khan, Lippincott, 2003. Radiation Oncology – Management Decisions, Chao, Lippincott, 2002.		

<table>
<tr><th>Course Title</th><th colspan="3">Radiation Protection</th></tr>
<tr><td>Course no.</td><td>3.2</td><td>Exam Regulations</td><td>45 min written exam</td></tr>
<tr><td>Credit Points</td><td>1.0</td><td>Formalities or Requirements for Participation</td><td>none</td></tr>
<tr><td>Workload</td><td>30 h</td><td>Max. Number of Participants</td><td>40</td></tr>
<tr><td>Type of Course</td><td>Lecture (mandatory)</td><td>Coordinator/Lecturer</td><td>V. Steil, PD Dr. C. Herskind</td></tr>
<tr><td>Turn</td><td>Yearly</td><td>Term</td><td>Winter</td></tr>
<tr><td>Language</td><td>English</td><td>Duration</td><td>Block course</td></tr>
<tr><td>Contents of Course:</td><td colspan="3">• Types and interactions of different ionizing radiations
• Medical and personal exposure
• Radiation shielding
• Regulations / Responsibilities
• International Radiation Protection</td></tr>
<tr><td>Learning Objectives</td><td colspan="3">After completing this course the students should be able to:
• understand and explain different radiation qualities,
• describe and explain principles and basics of radiation protection,
• estimate the risks of radiation,
• be aware of risk of radiation,
• have the competence for evaluating radiation protection, and estimate risk of radiation,
• know and apply legal regulations for radiation exposure.</td></tr>
<tr><td>Course Parts and Teaching Methods</td><td colspan="3">Lecture</td></tr>
<tr><td>Useful /Required Previous Knowledge</td><td colspan="3">General Knowledge Nuclear Physics, Radiation Physics</td></tr>
<tr><td>Recommended Literature</td><td colspan="3">Course book:
Radiation Oncology Physics: a Handbook for teachers and students. E.B. Podgorsak. 2005; http://www-pub.iaea.org/mtcd/publications/pdf/pub1196_web.pdf
complementary bibliography: http://www.icrp.org/
http://www.icrp.org/docs/Summary_B-scan_ICRP_60_Ann_ICRP_1990_Recs.pdf
resp. complete ICRP Report 60</td></tr>
</table>

<table>
<tr><td>Course Title</td><td colspan="3">Radiation Treatment Planning and Quality Assurance</td></tr>
<tr><td>Course no.</td><td>3.3</td><td>Exam Regulations</td><td>90 min written exam.</td></tr>
<tr><td>Credit Points</td><td>2.0</td><td>Formalities or Requirements for Participation</td><td>none</td></tr>
<tr><td>Workload</td><td>60</td><td>Coordinator / Lecturer</td><td>Dr. J. Fleckenstein</td></tr>
<tr><td>Type of Course</td><td>Lecture/ Practical Course (mandatory)</td><td>Max. Number of Participants</td><td>40</td></tr>
<tr><td>Turn</td><td>Yearly</td><td>Term</td><td>Winter</td></tr>
<tr><td>Language</td><td>English</td><td>Duration</td><td>Block course</td></tr>
<tr><td>Contents of Course:</td><td colspan="3">• 3D treatment planning
• dose calculation algorithms
• inverse planning and optimization (IMRT-VMAT) / dose prescription
• linear accelerator
• calibration/ acceptance and commissioning
• linear accelerator quality assurance
• patient specific quality assurance</td></tr>
<tr><td>Learning Objectives</td><td colspan="3">After completing this course the students are able to:
• describe relevant techniques in treatment planning and about the measurements of beam data,
• deal with terms: dose prescription, normalization and distribution,
• describe all steps in the chain in the 3D planning,
• describe relevant techniques in treatment planning,
• judge the plan quality using evaluation tools (Isodose lines, DVHs, statistics),
• describe the typical parameters which have to be checked in a linac QA program,
• perform typical QA measurements with dedicated detectors and analyse the results,
• explain measurement methods to check typical linac parameters,
• take relevant aspects, terms and definitions into account when setting up a QA program in a radiotherapy department.</td></tr>
<tr><td>Course Parts and Teaching Methods</td><td colspan="3">Lecture, and practical sessions: 3D-planning (4 h), Linac QA (4 h).</td></tr>
<tr><td>Useful /Required Previous Knowledge</td><td colspan="3">Radiation Protection</td></tr>
<tr><td>Recommended Literature</td><td colspan="3">Radiation Oncology Physics: a Handbook for teachers and students. E.B. Podgorsak. 2005 http://www-pub.iaea.org/mtcd/publications/pdf/pub1196_web.pdf
complementary bibliography:
Radiotherapy Physics: in Practice, Williams/Thwaites, Oxford University Press, 2000.
American association of physicists in medicine (AAPM) task group reports 51, 71, 106, 142, 2018, 265.
The Physics of Radiation Therapy, Faiz M. Khan, Lippincott, 2003.
ESTRO Publications:1. Monitor Unit Calculation for High Energy Photon Beams /2. Recommendations for a Quality Assurance Programme in External Radiotherapy /3. Practical Guidelines for the Implementation of a Quality System in Radiotherapy.</td></tr>
</table>

Course Title	**Treatment Planning and Quality Assurance Lab**		
Course no.	3.4	**Exam Regulations**	Data evaluation, report.
Credit Points	1.0	**Formalities or Requirements for Participation**	Participation in course 3.3.
Workload	30 h	**Coordinator / Lecturer**	Dr. J. Fleckenstein, Dr. S. Clausen, Dr. M. Polednik
Type of Course	Practical course/ Lab (elective)	**Max. Number of Participants**	20
Turn	Yearly	**Term**	Winter
Language	English	**Duration**	Block course
Contents of Course:	• Person dosimetry, radiation protection from architectural side. • Practical exercises for quality assurance of workflow and treatment planning system (system geometry, dosimetry). • Basic MU calculation. • Dosimetry with different detector systems (ionization chamber, solid state detector, film dosimeter) in different measurement systems (water phantom, water equivalent solid phantom etc.). • 3D planning. • QA Lab.		
Learning Objectives	After completing this course the students are able to: • apply their theoretical knowledge by measuring in phantoms for dosimetry and quality assurance, • do basic treatment and dose calculation for patient delivery, • describe the whole 3D planning chain, • prescribe dose in different ways, • generate plans with fix SSD and isocentric techniques, and • homogenize dose using different wedge thicknesses.		
Course Parts and Teaching Methods	Practical session at the Radiotherapy Department.		
Useful /Required Previous Knowledge	Students should apply basics in radiation protection in real situation / perform treatment planning / apply dosimetry / and perform quality assurance		
Recommended Literature	Radiation Oncology Physics: a Handbook for teachers and students. E.B. Podgorsak. 2005 http://www-pub.iaea.org/mtcd/publications/pdf/pub1196_web.pdf Complementary bibliography: A century in Radiology: http://www.xray.hmc.psu.edu/rci/ Radiotherapy Physics: in Practice, Williams/Thwaites, Oxford University Press, 2000. The Physics of Radiation Therapy, Faiz M. Khan, Lippincott, 2003.ESTRO Publications:1. Monitor Unit Calculation for High Energy Photon Beams /2. Recommendations for a Quality Assurance Programme in External Radiotherapy /3. Practical Guidelines for the Implementation of a Quality System in Radiotherapy.		

Course Title	Image Guided Radiotherapy		
Course no.	3.5	**Exam Regulations**	45 min written exam.
Credit Points	1.0	**Formalities or Requirements for Participation**	Successful participation in courses 3.1, 3.2 and 3.3.
Workload	30 h	**Coordinator / Lecturer**	Dr. F. Stieler
Type of Course	Lecture (elective)	**Max. Number of Participants**	40
Turn	Yearly	**Term**	Winter
Language	English	**Duration**	Block course
Contents of Course:	• Techniques of patient positioning and target location in radiation therapy (simulation, portal imaging, positioning support systems/mask systems), inaccuracies herein concerning positioning accuracy and dosimetry). • Localization by ultrasound margin concepts. • Localization by 2D X-ray (portal imaging, Fiducial markers). • 3D-CT (Cone Beam CT, Gantry Mounted Volume Imaging). • Motion management techniques.		
Learning Objectives	After completing this course the students are be able to: • describe the principles and basics of image guided radiotherapy, • explain a typical QA process for image guidance systems, • explain the typical workflow for IGRT for different systems, • name major goals of IGRT, • name uncertainties during radiotherapy such as set-up errors, organ movements or organ deformations.		
Course Parts and Teaching Methods	Lecture Practical session (4 h)		
Useful /Required Previous Knowledge	General Knowledge Nuclear Physics, Radiation Physics, imaging systems, radiation therapy		
Recommended Literature	Will be given at the beginning of the lecture.		

<table>
<tr><td>Course Title</td><td colspan="3">Special Radiotherapy Techniques</td></tr>
<tr><td>Course no.</td><td>3.6</td><td>Exam Regulations</td><td>90 min written exam.</td></tr>
<tr><td>Credit Points</td><td>2.0</td><td>Formalities or Requirements for Participation</td><td>Participation in courses 3.1, 3.2 and 3.3.</td></tr>
<tr><td>Workload</td><td>60 h</td><td>Coordinator / Lecturer</td><td>Dr. J. Fleckenstein, Dr. F. Stieler, Dr. C. Graeff, Dr. Kraft-Weyrather</td></tr>
<tr><td>Type of Course</td><td>Lecture (elective)</td><td>Max. Number of Participants</td><td>40</td></tr>
<tr><td>Turn</td><td>Yearly</td><td>Term</td><td>Winter</td></tr>
<tr><td>Language</td><td>English</td><td>Duration</td><td>Block course</td></tr>
<tr><td>Contents of Course:</td><td colspan="3">• Brachytherapy
• Intra Operative Radiotherapy (IORT)
• Total Body Radiation (TBI)
• Stereotactic radiotherapy
• Advanced delivery methods
• Particle therapy
• Adaptive radiation therapy (ART)</td></tr>
<tr><td>Learning Objectives</td><td colspan="3">After completing this course the students are able to:
• describe innovative radio-oncological methods for cancer treatment.
• asses a practically use of them depending on the disease of patient and available resources in a radiotherapy facility
• describe the principles and basics of “Seeds implantations” and “Afterloading”</td></tr>
<tr><td>Course Parts and Teaching Methods</td><td colspan="3">Lecture</td></tr>
<tr><td>Useful /Required Previous Knowledge</td><td colspan="3">General Knowledge radiation physics, radiation planning, Dosimetry and quality assurance in radiology and radiotherapy</td></tr>
<tr><td>Recommended Literature</td><td colspan="3">The GEC/ESTRO Handbook of Brachytherapy, Gerbaulet, ESTRO Publishing, 2002.
Intensity-Modulated Radiation Therapy, Webb, Institute of Physics Publishing, 2001.
Inverse planning algorithms for external beam radiation therapy, Chui, Med. Dosim, 2001.
AAPM Report on IMRT, Ezzell et al., Med. Phys. 30, 2003.
Radiation Oncology Physics: A Handbook for Teachers and Student, E.B. Podgorsak, INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2005.</td></tr>
</table>

<table>
<tr><td>Course Title</td><td colspan="3">Lab Medical Physics in Radiotherapy</td></tr>
<tr><td>Course no.</td><td>3.7</td><td>Exam Regulations</td><td>Presentation, report, exercises</td></tr>
<tr><td>Credit Points</td><td>5.0</td><td>Formalities or Requirements for Participation</td><td>Successful attendance in courses 3.1, 3.2, 3.3.</td></tr>
<tr><td>Workload</td><td>150 h</td><td>Coordinator / Lecturer</td><td>Dr. S. Clausen, Dr. J. Fleckenstein, Dr. M. Polednik, Dr. F. Stieler</td></tr>
<tr><td>Type of Course</td><td>Lab (elective)</td><td>Max. Number of Participants</td><td>12</td></tr>
<tr><td>Turn</td><td>Yearly</td><td>Term</td><td>Summer</td></tr>
<tr><td>Language</td><td>English</td><td>Duration</td><td>Block course</td></tr>
<tr><td>Contents of Course:</td><td colspan="3">• Practical exercises for quality assurance of workflow and treatment planning system (system geometry, dosimetry) – “end-to-end”-test.
• Dosimetry with different detector systems (ionization chamber, solid state detector, film dosimeter) in different measurement systems (water phantom, water equivalent solid phantom etc.).
• Patient treatment planning (different tumour sites).</td></tr>
<tr><td>Learning Objectives</td><td colspan="3">After completing this course the students are able to:
• describe the typical workflow for external radiotherapy with linacs,
• perform CT scans for different phantoms,
• design treatment plans and QA plans for different phantoms,
• deliver the QA plans with a linear accelerator,
• measure the QA plans with dedicated detector systems,
• analyse the results of the measurements with dedicated software,
• describe how an “End-to-End” test can be performed for checking a typical radiotherapy chain,
• create a scientific report about a given project.</td></tr>
<tr><td>Course Parts and Teaching Methods</td><td colspan="3">Practical session at the Radiotherapy Department including the dedicated computer tomography, the linear accelerator and the treatment planning systems available. A report must be submitted at the end of the lab.</td></tr>
<tr><td>Useful /Required Previous Knowledge</td><td colspan="3">General Knowledge radiation physics, radiation planning, Dosimetry and quality assurance in radiology and radiotherapy.</td></tr>
<tr><td>Recommended Literature</td><td colspan="3">Will be given at the beginning of the course.</td></tr>
</table>

Course Title	Seminar Radiation Therapy: Journal Club + Presentation		
Course no.	3.8	**Exam Regulations**	Presentation, min. 5 times presence in seminar.
Credit Points	2.0	**Formalities or Requirements for Participation**	Successful attendance in courses 3.1, 3.2, 3.3.
Workload	60 h	**Coordinator / Lecturer**	Dr. J. Fleckenstein
Type of Course	Seminar (elective)	**Max. Number of Participants**	12
Turn	Yearly	**Term**	Summer
Language	English	**Duration**	Block course
Contents of Course:	The topic depends on the current state of the art and the supervising lab. Workflow: • Attendance in the Journal Club Radiation Therapy (min. 5 times) • Presentation in Journal Club (1 time) • Report submission		
Learning Objectives	After completing this course the students are able to: • take part in scientific discussions, • work on literature research for a topic related to current state of the art in radiotherapy and related fields and present it, • create a suitable scientific presentation.		
Course Parts and Teaching Methods	• Attendance in the Journal Club Radiobiology (min. 5 times) • Presentation in Journal Club (1 time) • Report submission		
Useful /Required Previous Knowledge	General Knowledge radiation physics, radiation planning, Dosimetry and quality assurance in radiology and radiotherapy		
Recommended Literature	Will be given at the beginning of the course.		

Module 4. Medical Imaging

Course Title	**Physics of Imaging Systems**		
Course no.	4.1	**Exam Regulations**	90 min written exam.
Credit Points	2.0	**Formalities or Requirements for Participation**	none
Workload	60 h	**Coordinator / Lecturer**	Prof. Dr. L. Schad
Type of Course	Lecture (mandatory)	**Max. Number of Participants**	40
Turn	Yearly	**Term**	Winter
Language	English	**Duration**	Block course
Contents of Course:	Physical basics of imaging systems: • Conventional X-ray • Computer Tomography CT • Magnetic Resonance Imaging MRI. •		
Learning Objectives	After completing this course the students are able to: • describe the physical basics of imaging systems, • apply gained knowledge of image acquisition, processing and analysis, • optimize and develop further imaging technology.		
Course Parts and Teaching Methods	Lecture on imaging systems (4h/per week).		
Useful /Required Previous Knowledge	Basics in physics.		
Recommended Literature	Medical Imaging Physics, Hendee/Ritenour, Wiley-Liss, 2002. Bildgebende Systeme für die medizinische Diagnostik, Morneburg, 1995. Computertomographie. Grundlagen, Gerätetechnologie, Bildqualität, Anwendungen, Kalender, 2006.Magnetic Resonance Imaging Theory and Practice, Vlaardingerbroek /den Boer, 2003.		

Course Title	Biomedical Optics		
Course no.	4.2	Exam Regulations	45 min written exam.
Credit Points	1.0	Formalities or Requirements for Participation	Successful attendance in course 4.4.
Workload	30 h	Coordinator / Lecturer	Prof. Dr. L. Schad
Type of Course	Lecture (mandatory)	Max. Number of Participants	40
Turn	Yearly	Term	Winter
Language	English	Duration	Block course
Contents of Course:	Physical basics of biomedical optics: • Basics of geometrical optics: reflection- and refraction law, dispersion, polarization • Physical basics of optics: particle/wave duality, Maxwell laws • Basics of laser physics: principals, interaction with matter, laser-properties and –systems • Biomedical applications: lasers in medicine, microscopy, etc.		
Learning Objectives	After completing this course the students are able to: • describe basic physical principles in optics and lasers, • select appropriate hardware for biomedical experiments using optics, • experiment with laser systems in medical applications.		
Course Parts and Teaching Methods	Lecture		
Useful /Required Previous Knowledge	Basics in physics and optics.		
Recommended Literature	E. Hecht and A. Zajac, Optics, Addison Wesley, International 4th ed., 2003. M. Born and E. Wolf, Principles of optics: Electromagnetic theory of propagation, Cambridge University Press, 2002. M.H. Niemz, Laser-Tissue Interactions: Fundamentals and Applications (Biomedical and Medical Physics, Biomedical Engineering), Springer, 3rd enlarged ed., 2003. L.O. Björn, Photobiology, Springer, 2008.		

Course Title	Biomedical Engineering		
Course no.	4.3	Exam Regulations	90 min written exam.
Credit Points	2.0	Formalities or Requirements for Participation	Successful attendance in course 1.1.
Workload	60 h	Coordinator / Lecturer	Prof. Dr. L. Schad, Dr. J. Chacón, A. Schnurr
Type of Course	Lecture (mandatory)	Max. Number of Participants	40
Turn	Yearly	Term	Winter
Language	English	Duration	Block course
Contents of Course:	• Measuring Electrical Signals, Electrodes and Noise • Amplifiers, Biomagnetism and Transducers Evoking • Physiological Responses: Stimuli and Detection • Electrophysiology: Measurements, Techniques and Modelling • Image Formation: Point Spread function, Noise, Fourier Transform • Sonography: Physics of Sound, Imaging and Therapy • Fluid Dynamics, Blood Flow and Pressure • 3D Printing: Principles and Applications • Machine Learning: Classification, Segmentation and Regression		
Learning Objectives	After completing this course the students are able to: • describe fundamental principles of biomedical engineering topics • design and perform experiments in this field • model and solve simple systems in the biomedical field		
Course Parts and Teaching Methods	Lecture to teach the basic concepts.		
Useful /Required Previous Knowledge	Basics in Physics and Mathematics.		
Recommended Literature	Medical Physics and Biomedical Engineering, Brown et al., 1999.		

Course Title	Basic Optics and Laser		
Course no.	4.4	Exam Regulations	45 min written exam.
Credit Points	1.0	Formalities or Requirements for Participation	Successful participation in M1, course 2.1, and 2.2.
Workload	30	Coordinator / Lecturer	Prof. Dr. J. Bille
Type of Course	Lecture (elective)	Max. Number of Participants	40
Turn	Yearly	Term	Winter
Language	English	Duration	Block course
Contents of Course:	• Geometric optics: reflection, refraction, dispersion, polarization • Optical aberration • Gauss-optics • Diffraction optics • Interferometry • Optical resolution, human eye, optical instruments.		
Learning Objectives	After completing this course the students are able to: • explain the basic elements of geometric optics apply lens equations for optical systems, diffraction theory, • are able to perform interfereometrical measurement methods.		
Course Parts and Teaching Methods	Lecture on optics.		
Useful /Required Previous Knowledge	General knowledge in optics.		
Recommended Literature	E. Hecht, Physics, Brooks/Cole Publishing Company,1994. P. Tipler, Physics, Worth Publishers Inc., 1982. M. Born and E. Wolf, Principles of optics: Electromagnetic theory of propagation, Cambridge University Press, 2002.		

Course Title	**MR-Radiology Lab**		
Course no.	4.5	**Exam Regulations**	Presentation and data evaluation.
Credit Points	1.0	**Formalities or Requirements for Participation**	Successful attendance in course 4.1 (in case of high demand participants will be selected on the basis of their exam results of course 4.1.).
Workload	30 h	**Coordinator / Lecturer**	Prof. Dr. L. Schad
Type of Course	Practical course/ Lab (elective)	**Max. Number of Participants**	20
Turn	Yearly	**Term**	Winter
Language	English	**Duration**	Block course
Contents of Course:	• Practical training in image acquisition with MRI (phantom experiments) • Characteristics of conventional imaging sequences regarding tissue contrast, artefacts (T1, T2) • Characteristics of fast imaging sequences • Application of special sequences (angiography, diffusion tensor imaging, functional MRI).		
Learning Objectives	After completing this course the students are able to: • apply gained experimental knowledge on MRI in their own scientific or work related projects, • perform MRI scans, • process and analyse MR images.		
Course Parts and Teaching Methods	Lab will be performed at a clinical whole body scanner.		
Useful /Required Previous Knowledge	Basics in physics and MRI.		
Recommended Literature	Medical Imaging Physics, Hendee/Ritenour, Wiley-Liss, 2002.		

Course Title	**Seminar MR Methods and Technology: Journal Club + Presentation**		
Course no.	4.6	**Exam Regulations**	Presentation, report and min. 5 times presence in seminar.
Credit Points	2.0	**Formalities or Requirements for Participation**	Successful attendance in course 4.1 (In case of high demand participants will be selected on the basis of their exam results of course 4.1. This optional supplementary course is offered in German or English, depending on speaker, and can be chosen by students with German language skills who plan to work in a German speaking environment).
Workload	60 h	**Coordinator / Lecturer**	Prof. Dr. F. Zöllner
Type of Course	Seminar (elective)	**Max. Number of Participants**	5
Turn	Half-yearly	**Term**	Winter/Summer
Language	German/English	**Duration**	Weekly course
Contents of Course:	The topic depends on the current state of the art in imaging techniques.		
Learning Objectives	After completing this course the students are able to: • take part in scientific discussions • formulate a topic related to the current state of the art • present current research topics		
Course Parts and Teaching Methods	Workflow: • Attendance in the Journal Club (min. 5 times) • Presentation in Journal Club (1 time) • Report submission.		
Useful /Required Previous Knowledge	Basics in physics and mathematics.		
Recommended Literature	Will be given at the beginning of the course.		

Course Title	Nuclear Medicine + Exercises		
Course no.	4.7	Exam Regulations	90 min written exam.
Credit Points	4.0	Formalities or Requirements for Participation	Successful participation in courses 3.1, 3.2, and 4.1.
Workload	120 h	Coordinator / Lecturer	Dr. Laura Reffert
Type of Course	Lecture with exercises (mandatory)	Max. Number of Participants	40
Turn	Yearly	Term	Winter
Language	English	Duration	Block course
Contents of Course:	• Basics of radioactive decay • Production of radionuclides • Basic physics of imaging and therapy with radioactive substances • Basic radiochemistry / radiopharmacy • Nuclear medicine instrumentation (gamma camera, SPECT, PET) • Clinical nuclear medicine (scintigraphy, immunoscintigraphy, SPECT, PET) and combination with other modalities (PET/CT, SPECT/CT) • Modelling in nuclear medicine • Molecular radiotherapy (radioiodine therapy, radioimmunotherapy, peptide receptor radionuclide therapy) • Evaluation of diagnostic systems • Combination of nuclear medicine and other modalities • Applications, guided radiochemistry tour		
Learning Objectives	After completing this course the students are able to: • explain the fundamentals of radioactive decay and how radionuclides can be artificially produced • describe and explain the principles used in nuclear medicine and the function of the imaging devices, • describe the desired characteristics of radionuclides and how they are incorporated in molecular targets (=radiopharmaceutical) • analyse malfunctions of imaging devices using the acquired concepts and techniques, to formulate models and find solutions to specific problems, and to communicate them efficiently, • perform a basic dosimetry and treatment planning in molecular radiotherapy, • evaluate diagnostic systems with respect to basic imaging characteristics.		
Course Parts and Teaching Methods	Lecture on Medical Physics in “Nuclear Medicine” (16 hours). Exercises (8 hours).		
Useful /Required Previous Knowledge	Knowledge in radiation physics and medical imaging.		
Recommended Literature	Will be given at the beginning of the course.		

Course Title	**Lab Medical Physics in Imaging**		
Course no.	4.8	**Exam Regulations**	Presentation and report.
Credit Points	5.0	**Formalities or Requirements for Participation**	Successful attendance in courses 4.1. (in case of high demand participants will be selected on the basis of their exam results of course 4.1).
Workload	150 h	**Coordinator / Lecturer**	Prof. Dr. L. Schad
Type of Course	Practical course/Lab (elective)	**Max. Number of Participants**	18
Turn	Yearly	**Term**	Summer
Language	English	**Duration**	Block course
Contents of Course:	• MRI hardware setup • Basic settings and preparation of MRI system (frequency adjustments, flip angle, shim) • Recording FID signal, influence on the signal, etc. • Relaxation time measurements and data analysis in probes of water and oil		
Learning Objectives	After completing this course the students are able to: • describe the principle of the MR signal generation and relaxation concept, • apply gained experimental knowledge on MRI in their own scientific or work related projects, • perform MRI scans, • calculate relaxation time constants from MR datasets.		
Course Parts and Teaching Methods	Introduction to the course content and the handling of a table top MRI system. Practical part in small groups using the table top MRI system.		
Useful /Required Previous Knowledge	Basics in physics.		
Recommended Literature	A dedicated script describing the experiments to be performed by the students will be provided at the start of the course.		

Course Title	Seminar Physics of Advanced MRI / CT Techniques		
Course no.	4.9	**Exam Regulations**	Presentation, report and 75% attendance.
Credit Points	6.0	**Formalities or Requirements for Participation**	Successful attendance in course 4.1. (external course, specific admission requirements may apply. (This optional supplementary course is offered in German and can be chosen by students with German language skills who plan to work in a German speaking environment).
Workload	180 h	**Coordinator / Lecturer**	Prof. Dr. L. Schad, Dr. J. Zapp, Dipl.-Phys. M. Ruttorf
Type of Course	Seminar (elective)	**Max. Number of Participants**	5 (external course, specific admission requirements may apply)
Turn	Yearly	**Term**	Summer
Language	German	**Duration**	Weekly course
Contents of Course:	• The topic depends on the current state of the art in physical basics of imaging and/or diagnostic techniques including MRI and CT • Respective papers are selected and distributed among the attendees.		
Learning Objectives	After completing this course the students are able to: • take part in scientific discussions, • formulate a topic related to the current state of the art, • present current research topics.		
Course Parts and Teaching Methods	Workflow: • Attendance in the Journal Club (75%) • Presentation in Journal Club (1 time) • Report submission.		
Useful /Required Previous Knowledge	Basics in physics and medical imaging systems.		
Recommended Literature	Will be given at the beginning of the course.		

Course Title	**Advanced Imaging Techniques**		
Course no.	4.10	**Exam Regulations**	90 min written exam.
Credit Points	2.0	**Formalities or Requirements for Participation**	Successful attendance in module M1 and course 4.1.
Workload	60 h	**Coordinator / Lecturer**	Prof. Dr. L. Schad, Prof. Dr. F. Zöllner
Type of Course	Lecture (mandatory)	**Max. Number of Participants**	40
Turn	Yearly	**Term**	Winter
Language	English	**Duration**	Weekly course
Contents of Course:	Physical foundations of advanced imaging techniques: • Perfusion Imaging & Pharmacokinetic Modelling • Diffusion MRI • X-Nuclei Imaging • Dual energy CT • Iterative Reconstruction Techniques in CT/CBCT.		
Learning Objectives	After completing this course the students are able to: • describe thoroughly advanced MRI and CT imaging methods, • apply these techniques in scientific or work related tasks, • analyse imaging data previously acquired.		
Course Parts and Teaching Methods	Lecture with exercises.		
Useful /Required Previous Knowledge	Basics in medical imaging.		
Recommended Literature	Will be given at the beginning of the course.		

Course Title	Medical Devices and Imaging Systems		
Course no.	4.11	**Exam Regulations**	120 min written exam.
Credit Points	4.0	**Formalities or Requirements for Participation**	Successful attendance in course 4.1 (external course, specific admission requirements may apply. (This optional supplementary course is offered in German and can be chosen by students with German language skills who plan to work in a German speaking environment).
Workload	120 h	**Coordinator / Lecturer**	Prof. Dr. L. Schad, M.Sc. T. Uhrig, M.Sc. S. Thomas, M.Sc. R. Hu
Type of Course	Lecture (elective)	**Max. Number of Participants**	5 (external course, specific admission requirements may apply)
Turn	Half-yearly	**Term**	Winter/Summer
Language	German	**Duration**	Weekly course
Contents of Course:	• Basic physics of MRI • Concept of spin relaxation • Pulse sequences • Hardware for MRI • Image coding using gradient system. k-space MRI applications		
Learning Objectives	After completing this course the students are able to: • describe and report on the fundamental details of MRI, • describe advanced imaging concepts in MRI, • apply this knowledge in their scientific projects or work related duties.		
Course Parts and Teaching Methods	Lecture to teach the theoretical aspects. Exercises to rehearse the lectures. Labs including experiments on a table top MRI and a visit at a clinical whole-body system.		
Useful /Required Previous Knowledge	Basics in physics.		
Recommended Literature	Spin Dynamics: Basics of Nuclear Magnetic Resonance, Levitt, Wiley, 2001. Magnetic Resonance Imaging Theory and Practice, Vlaardingerbroek / den Boer, 2003.		

Course Title	MRT Basics		
Course no.	4.12	Exam Regulations	90 min written exam.
Credit Points	2.0	Formalities or Requirements for Participation	Successful attendance in module 4.1 (external course, specific admission requirements may apply. This optional supplementary course is offered in German and can be chosen by students with German language skills who plan to work in a German speaking environment).
Workload	Lecture 30 h, self-study 20 h, and preparation for exam 10 h.	Coordinator / Lecturer	Prof. Dr. L. Schad
Type of Course	Lecture (elective)	Max. Number of Participants	5 (external course, specific admission requirements may apply)
Turn	Yearly	Term	Winter
Language	German	Duration	Weekly course
Contents of Course:	aging in MRI		
Learning Objectives	After completing this course the students are able to: • describe and report on the fundamental details of MRI • describe advanced imaging concepts in MRI • apply this knowledge in their scientific projects or work related duties		
Course Parts and Teaching Methods	Lecture		
Useful /Required Previous Knowledge	Basics in physics.		
Recommended Literature	Magnetic Resonance Imaging Theory and Practice, Vlaardingerbroek/ den Boer, 2003.		

Course Title	X-Ray Diagnostics and Sonography		
Course no.	4.13	**Exam Regulations**	2 x 90 min written exam. Exam dates will be announced during the course.
Credit Points	2.0	**Formalities or Requirements for Participation**	Successful attendance in course 4.1. (external course, specific admission requirements may apply. This optional supplementary course is offered in German and can be chosen by students with German language skills who plan to work in a German speaking environment).
Workload	Lecture 30 h, self-study 20 h, and preparation for exam 10 h.	**Coordinator / Lecturer**	Prof. Dr. L. Schad/ Prof. Dr. F. Zöllner
Type of Course	Lecture (elective)	**Max. Number of Participants**	5
Turn	Yearly	**Term**	Winter
Language	German	**Duration**	Weekly course
Contents of Course:	Advanced techniques of Imaging Systems/ Diagnostics • Conventional X-ray • Sonography/ Ultrasound		
Learning Objectives	After completing this course the students are able to: • describe or report on the physical basics of conventional X-ray and Sonography.		
Course Parts and Teaching Methods	Lecture		
Useful /Required Previous Knowledge	Basics in physics.		
Recommended Literature	Medical Imaging Physics, Hendee/Ritenour, Wiley-Liss, 2002.		

Module 5. Computational Medical Physics

Course Title	Image Analysis + Exercises		
Course no.	5.1	Exam Regulations	Oral exam.
Credit Points	4.0	Formalities or Requirements for Participation	Successful attendance in course 1.2 and 4.1.
Workload	120 h	Coordinator / Lecturer	Prof. Dr. J. W. Hesser
Type of Course	Lecture (mandatory)	Max. Number of Participants	40
Turn	Yearly	Term	Winter
Language	English	Duration	Weekly course
Contents of Course:	• Digitization of image information/ relevant data formats • Mathematical methods of image transformation, digital filtering (linear, non-linear), Fourier- transform, segmentation, registration and pattern recognition.		
Learning Objectives	After completing this course the students are able to: • explain the principles using image analysis and apply this knowledge in concrete practical applications, • solve image analysis tasks covered by this course, i.e. the ability to apply the image processing workflow using the acquired concepts and techniques, to formulate models and find solutions to specific problems, and to communicate them efficiently, • systematically study and describe current literature and thus solve new image analysis problems.		
Course Parts and Teaching Methods	Lecture		
Useful /Required Previous Knowledge	none		
Recommended Literature	Medical Image Processing, Gonzalez/Woods/Eddin, Pearson, 2004.		

Course Title	Matlab Programming		
Course no.	5.2	Exam Regulations	Exam (Written / Oral / Exercises / Report).
Credit Points	4.0	Formalities or Requirements for Participation	none
Workload	120 h	Coordinator / Lecturer	Prof. Dr. J. W. Hesser
Type of Course	Lecture / Practical course (elective)	Max. Number of Participants	40
Turn	Yearly	Term	Winter
Language	English	Duration	Block course
Contents of Course:	• User interfaces • Advanced Matlab programming skills • Typical applications where Matlab is applied in the master thesis		
Learning Objectives	After completing this course the students are able to: • explain the principles using advanced programming techniques and apply this knowledge in concrete practical applications • solve programming tasks covered by this course, i.e. the ability to apply numerical methods using the acquired concepts and techniques, to formulate models and find solutions to specific problems, and to communicate them efficiently, • systematically study and describe current literature and solve new problems with this extended knowledge.		
Course Parts and Teaching Methods	Lecture with practical sessions. The exercises should be solved with tutoring advice.		
Useful /Required Previous Knowledge	Basic knowledge of programming in Matlab.		
Recommended Literature	http://www.lmsc.ethz.ch/Teaching/ipss_2010/advancedProgramming.pdf http://jagger.berkeley.edu/~pack/e177/ http://www.mathworks.cn/programs/downloads/presentations/MasterClassA_AdvancedProgramming.pdf		

Course Title	Simulators in Games and Medicine + Exercises		
Course no.	5.3	Exam Regulations	Exam (Written / Oral / Exercises / Report).
Credit Points	8.0 3 (Lecture) 5 (Exercises)	Formalities or Requirements for Participation	none
Workload	240 h	Coordinator / Lecturer	Prof. Dr. J. W. Hesser
Type of Course	Lecture and Exercise (elective)	Max. Number of Participants	40
Turn	Yearly	Term	Summer
Language	English	Duration	Block course
Contents of Course:	• Basic components of simulation engine (games) • Architecture of games engines • Introduction of OGRE as an open-source game engine • Overview: graphics and computer games • Collision engine • Animation and physics engine (open-source library Bullet) • Path planning engine • AI (artificial intelligence) engine		
Learning Objectives	After completing this course the students are able to: • explain the principles used in computer game engines in order to be able to develop an own game engine • assess efficient and suited solutions for given problems in the interdisciplinary field of computer games • develop serious game applications including graphics systems, physics systems, and AI-systems, and to communicate this efficiently, • systematically study and describe current literature in order to apply the newly learned techniques to given or new tasks.		
Course Parts and Teaching Methods	Lecture / Exercises		
Useful /Required Previous Knowledge	Background in C++ of advantage		
Recommended Literature	Gregory et al: Game Engine Architecture. Ericson: Real-Time Collision Detection. Eberly: Game Physics. Millington: Artificial Intelligence for Games.		

Course Title	Volume Visualization + Exercises		
Course no.	5.4	**Exam Regulations**	Exam (Written / Oral / Exercises / Report).
Credit Points	8.0 2 (Lecture) 6 (Exercises)	**Formalities or Requirements for Participation**	none
Workload	240 h	**Coordinator / Lecturer**	Prof. Dr. J. W. Hesser
Type of Course	Lecture (elective)	**Max. Number of Participants**	40
Turn	Yearly	**Term**	Summer
Language	English	**Duration**	Block course
Contents of Course:	• Computer Graphics basics • Conversion into surface and volume grids • Sampling and approximation theory • Volume rendering • Vector and information visualization • Programming technique: GPU- programming		
Learning Objectives	After completing this course the students are able to: • explain the principles used in visualizing scalar scientific data in order to develop visualization strategies for given problems, • assess the most appropriate technique for a given problem in the interdisciplinary field of volume visualization, • analyse data, interpolate data and extract useful information using the acquired concepts and techniques, to formulate models and find solutions to specific problems, and to communicate them efficiently, • systematically study and describe current literature in order to apply the newly learned techniques to given or new tasks.		
Course Parts and Teaching Methods	Lecture / Exercises		
Useful /Required Previous Knowledge	Background in C++ of advantage.		
Recommended Literature	Engel et al: Real-Time Volume Graphics: www.real-time-volume-graphics.org, Schroeder et al: VTK Textbook: http://www.kitware.com/products/books/vtkbook.html		

Course Title	**Inverse Problems + Exercises**		
Course no.	5.5	**Exam Regulations**	Exam (Written / Oral / Exercises / Report).
Credit Points	8.0 2 (Lecture) 6 (Exercises)	**Formalities or Requirements for Participation**	none
Workload	240 h	**Coordinator / Lecturer**	Prof. Dr. J. W. Hesser
Type of Course	Lecture and Exercise (elective)	**Max. Number of Participants**	40
Turn	Yearly	**Term**	Summer
Language	English	**Duration**	Block course
Contents of Course:	• Examples of inverse problems, especially tomography and deblurring • Deterministic approaches, Tikhonov regularization • Stochastic methods (Bayesian techniques) • Estimating the regularization parameter • Compressed sensing		
Learning Objectives	After completing this course the students are able to: • explain the principles used in inverse problems and are able to apply this to a given problem, • correctly identify the most suited method for a given task in the interdisciplinary field of inverse problems, • analyse given inverse problems and find appropriate solvers and regularization techniques, • systematically study and describe current the literature in order to apply the new techniques to given or new problems.		
Course Parts and Teaching Methods	Lecture / Exercises		
Useful /Required Previous Knowledge	None		
Recommended Literature	Vogel: Computational Methods for Inverse Problems. http://www.math.montana.edu/~vogel/Book/		

Course Title	Computational Medical Physics Lab		
Course no.	5.6	**Exam Regulations**	Presentation / Report / Exercises / Exam.
Credit Points	5.0	**Formalities or Requirements for Participation**	none
Workload	150 h	**Coordinator / Lecturer**	Prof. Dr. J. W. Hesser
Type of Course	Lab (elective)	**Max. Number of Participants**	12
Turn	Yearly	**Term**	Summer
Language	English	**Duration**	Block course
Contents of Course:	• Methods of non-linear numerical analysis – eLearning-course • GPU programming – hands-on-course with examples • Mathematical models in medical physics and biomedical optics such as – eLearning course		
Learning Objectives	After completing this course the students are able to: • explain the principles used in computational medical physics and are able to apply this to a given problem, • correctly identify the most suited method for a given task, • systematically study and describe current the literature in order to apply the new techniques to given or new problems.		
Course Parts and Teaching Methods	Lab		
Useful /Required Previous Knowledge	none		
Recommended Literature	Will be given at the beginning of the course.		

Module 6. Abroad Courses

Course Title	**Shanghai Workshop**		
Course no.	6.1	**Exam Regulations**	Presentation / Oral exam.
Credit Points	1.0	**Formalities or Requirements for Participation**	none
Workload	30 h	**Coordinator /Lecturer**	Director Department of Radiation Oncology, Prof. Dr. J. W. Hesser
Type of Course	Workshop (elective)	**Max. Number of Participants**	20
Turn	Yearly	**Term**	Summer
Language	English	**Duration**	Block course
Contents of Course:	The schedule of the workshop in Shanghai covers one week. Both Shanghai Jiao Tong University and Mannheim Faculty, University of Heidelberg, provide about 8-hour lectures. The lectures cover the topics: • Radiotherapy, Nuclear Medicine: - Modern Radiation Oncology (Shanghai Jiao Tong University) - Image Guided Radiotherapy (University of Heidelberg) - Hyperthermia (University of Heidelberg). • Biomedical Optics (Shanghai Jiao Tong University) Additionally, the students join the “Annual Sino-German Radiation Oncology Symposium”.		
Learning Objectives	After completing this course the students are able to: • name and explain recent developments and current research activities in radiotherapy and biomedical optics, • communicate with students from other institutions about radiotherapy and biomedical optics, • use their broadened knowledge in culture in order to efficiently conduct mutual research projects between both institutions to solve typical problems in biomedical engineering.		
Course Parts and Teaching Methods	Attendance of lecture and the Sino-German workshop in Shanghai, China. At the end of the workshop there will be an oral examination.		
Useful /Required Previous Knowledge	Basic knowledge of programming in Radiotherapy.		
Recommended Literature	Will be given at the beginning of the workshop.		

Module 7. Master Thesis Preparation

Course Title	**General Sciences Skills**		
Course no.	7.1	**Exam Regulations**	Presentation / Report /Protocol
Credit Points	3.0	**Formalities or Requirements for Participation**	n/a
Workload	90 h	**Coordinator / Lecturer**	Prof. Dr. P. Maier, Prof. Dr. M. R. Veldwijk
Type of Course	Workshop (mandatory)	**Max. Number of Participants**	20
Turn	Yearly	**Term**	Winter
Language	English	**Duration**	Block course
Contents of Course:	The students receive a topic/theme (i.e. future master thesis topic). • Following the theme, the students work on the state of the art, write a short report and present it. • The students learn how to get new ideas through special techniques like brainstorming. They have to structure these ideas and develop a research plan/proposal. A report has to be written. A tutor will introduce the students to each task and will guide them through their work.		
Learning Objectives	After completing this course the students are able to: • plan a scientific work • gain information about the state of the art in an specific scientific field related to any of the three specialization offered in the master program • write and review grant proposals and how to gain new ideas in a research field.		
Course Parts and Teaching Methods	Lecture / Report / Presentation.		
Useful /Required Previous Knowledge	none		
Recommended Literature	Will be given at the beginning of the course.		

Course Title	**Specialized Lab Project**		
Course no.	7.2	**Exam Regulations**	Report
Credit Points	16.0	**Formalities or Requirements for Participation**	Formal registration / Successful attendance in General Science Skills (course 7.1.)
Workload	480 h	**Coordinator / Lecturer**	depends on the supervising department
Type of Course	Scientific lab (mandatory)	**Max. Number of Participants**	40
Turn	Yearly	**Term**	Winter
Language	English	**Duration**	3-month block course
Contents of Course:	• The topic depends on the supervising department. • The project should introduce into a special field of application		
Learning Objectives	After completing this course the students are able to: • apply the knowledge learned in theoretical courses in a practical application that is related to the foci of the BME-study program. • apply given techniques to solve practical problems including e.g. the scientific approach, protocol writing of experiments • perform a scientifically oriented master thesis.		
Course Parts and Teaching Methods	This course can be a preparation for the master's thesis. The students should search by him/her self for a topic of his/her interests approaching any of the research groups belonging to any of the specializations offered in the Master Program. External projects or internships are also possible after competition of internal requirements.		
Useful /Required Previous Knowledge	Basic knowledge in radiation oncology, medical imaging or computational medical physics		
Recommended Literature	Provided by the supervisor of the project		

Module 8. Master Thesis

Course Title	Master Thesis		
Course no.	8.1	Exam Regulations	Written thesis, colloquium (public oral presentation with discussion), final oral examination about thesis and whole content of the attended lectures.
Credit Points	30.0	Formalities or Requirements for Participation	Formal registration / Successful attendance in all modules M1, M 2, M7 and specialized courses from M3, M4, M5 (related to the individual specialization of the student).
Workload	900 h	Coordinator / Lecturer	Independent scientific work (supervised).
Type of Course	Thesis (mandatory)	Max. Number of Participants	40
Turn	Yearly	Term	Summer
Language	English	Duration	6-month block course
Contents of Course:	The topic and contents depend on the supervising department.		
Learning Objectives	After completing this course the students are able to: • work independently on a scientific topic, guided by a tutor, • search and analyse literature, • formulate / organize and perform an experiment.		
Course Parts and Teaching Methods	Master project and thesis		
Useful /Required Previous Knowledge	Subject-related basic knowledge and completion of all selected courses amounting to 90 ECTS.		
Recommended Literature	Topic-related		