FH AACHEN
UNIVERSITY OF APPLIED SCIENCES

Modulhandbuch

Master Nuclear Applications

Prüfungsordnung 2020

updated on 15.03.2023

Inhaltsverzeichnis (Table of Contents)

Allgemeine Module

Modul 1: Fundamentals of Nuclear Science

Kennnum-mer	Workload	Credits	Studien-semester	Häufigkeit des Angebots	Dauer
310330	150 h	5	1. Sem.	Wintersemester/ Sommersemester	1 Semester

1	**Lehrveranstaltungen** Fundamentals of Nuclear Science a) Lecture (2 SWS) b) Exercise (2 SWS)	**Kontaktzeit** 4 SWS / 60 h	**Selbststudium** 90 h	**geplante Gruppengröße** 20

2 Lernergebnisse (learning outcomes) / Kompetenzen

This course teaches students basic principles of nuclear science. The students understand fundamental concepts of physics that are relevant to nuclear science. They are able to explain the atomic nucleus, its constituents, and nuclear performance. They can predict nuclear stability based on a basic understanding of nuclear models and calculations. Students can apply the chart of the nuclides as a data resource. They are capable of calculating the energies of nuclear transformations and predict the outcome of nuclear decay and nuclear reactions in a quantitative way. The students are familiar with the time laws of radioactive decay including radioactive equilibrium. They have a basic understanding of nuclear fission and fusion reactions and of the facilities needed for nuclear reactions.

3 Inhalte

- Fundamental and modern physics concepts relevant to nuclear science
- Atom Models
- Nuclear Energetics
- Radioactive Decay
- Binary Nuclear Reactions
- Nuclear Reactors
- Fusion Reactors
- Accelerators

4 Lehrformen

lecture, exercise, self-study (in the summer semester only self-study with exercise)

5 Teilnahmevoraussetzungen

formal conditions: none

information on preparation: none

6 Prüfungsformen

Written exam (120 min)

7 Voraussetzungen für die Vergabe von Kreditpunkten

	Passed module exam
8	**Verwendung des Moduls** (in anderen Studiengängen) none
9	**Stellenwert der Note für die Endnote** 4.17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** Prof. Dr. Paulßen, Prof. Dr. Ziemons, Prof. Dr. Langer
11	**Sonstige Informationen** **Literatur und Lernunterlagen** Fundamentals of Nuclear Science and Engineering, 3rd Edition, from J. Kenneth Shultis and Richard E. Faw (CRC Press, 2017)

Modul 2: Radiation Detection

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
310220	150 h	5	1. Sem.	Wintersemester/ Sommersemester	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	Detection of Nuclear Radiation a) Lecture (2 SWS) b) Practical Training (2 SWS)	4 SWS / 60 h	90 h	Lecture: 20 Practical Training: 10

2	**Lernergebnisse (learning outcomes) / Kompetenzen** Students understand the interaction of nuclear radiations with matter and based thereupon the working principles of common detectors for nuclear radiations. They know the construction and function of these detectors and the associated counting electronics. They are capable of practically measuring nuclear radiations with common detector types in standard applications. They can select and set up proper instrumentation required for a given measurement task.
3	**Inhalte** The main contents of this course are: • Interaction of radiation with matter • Charged particle (heavy ions and electrons) interactions • Gamma-ray interaction principles • Neutron detection mechanism

	• Statistical principles • Detection devices like Gas-Filled Detectors, Scintillators, LSC, Semiconductor Detectors used in different applications • Practical training
4	**Lehrformen** lecture, practical training, self-study (in the summer semester only self-study with practical training)
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** Written exam (90 min) or oral exam (30 min) depending on student number
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed module exam Passed lab course
8	**Verwendung des Moduls** (in anderen Studiengängen) none
9	**Stellenwert der Note für die Endnote** 4.17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** Prof. Dr. Langer
11	**Sonstige Informationen** **Literatur und Lernunterlagen** additional course information can be found on ILIAS

Modul 3: Fundamental Skills 1

Kennnummer	**Workload**	**Credits**	**Studiensemester**	**Häufigkeit des Angebots**	**Dauer**
310340	150 h	5	1. Sem.	Wintersemester	1 Semester

1	**Lehrveranstaltungen** 1. Basic Radiation Biology (310041) a) Lecture (2 SWS) 2. Radiation Safety (335130)	**Kontaktzeit** 4 SWS / 60 h	**Selbststudium** 90 h	**geplante Gruppengröße** 20

	a) Lecture (1 SWS) b) Practical Training (1 SWS)			

2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. The students know the basic interaction mechanisms of ionizing radiation with living cells and tissues. They can describe the consequences of exposure to ionizing radiation on different organization levels such as biomolecules, cells, tissues, organs and organisms. 2. The students can apply the basic quantities and units of ionizing radiation as well as the rules and principles of radiation protection. They know radiation protection regulations and organizations. The students use the shielding theory and the corresponding computational methods. They are able to select typical shielding materials for different radiation sources and are finally able to simulate shielding problems with MCNP and estimate the results. Due to the practical training the students can apply dose and contamination detectors. They are able to detect contaminations, can analyze those and decide on a suitable method of decontamination.
3	**Inhalte** 1. Biological effects of radiation (initial interactions; dose, dose rate, and dose distribution; damage to critical targets, organelles, cell types, tissues, organs, whole organisms and populations (genetic risks); risk assessment). This includes ionization of biomolecules and radical formation, the oxygen effect; protective mechanisms and and sensitization), radiation cell damage and DNA damage response (DNA damage, DNA repair mechanisms, radiation induced cell death and loss of reproductive capacitycell division delay; cell cycle arrests. Stochastic and deterministic damage. 2. Basic quantities and units of ionizing radiation, Rules and principles of radiation protection, Radiation protection regulations and organizations, Shielding materials, Decontamination methods, Basic methods for radiation dose calculations, Applications of MCNP simulation (calculation of the dose rate map)
4	**Lehrformen** 1. Lecture, Self-Study 2. Lecture, Practical Training, Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Written exam (60 min) 2. Written exam (60 min) and written assignment (appr. 10 slides, e.g. with powerpoint)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** 1. Passed module exam 2. Passed module exam, passed practical training
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4.17 %

10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Ziemons **Lehrende:** 1. Dr. Kriehuber 2. Dr. Li
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. Radiation Biology a) Nias, A.H.W. : An Introduction to Radiobiology b) Hall, E. Radiobiology for the Radiologist c) Steel G. Basic Clinical Radiobiology d) IAEA, Radiation biology: A Handbook for Teachers and Students 2. Radiation Safety a) James E. Martin, Physics for Radiation Protection (ISBN 978-3-527-41176-4) b) Haydee Domenech, Radiation Safety (ISBN 978-3-319-42669-3) c) J. Kenneth Shultis and Richard E. Faw, Radiation Shielding (ISBN 0-89448-456-7) d) MCNP Primer

Modul 4: Fundamental Skills 2

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
320070	150 h	5	1. Sem.	Wintersemester	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	1. Research Planning & Scientific Writing (320210) a) Lecture (3 SWS) 2. Presentation and Discussion Techniques (320230) a) Seminar (2 SWS)	5 SWS / 75 h	75 h	20

2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. Students understand the principles of scientific working. They can plan and structure a research project. They know how to search scientific databases for literature. They have understood the structure of scientific papers and are able to write their sections. They are aware of the tools available for scientific working. 2. Students can prepare and write a presentation on self-chosen scientific topics that relate to the different focuses of the study. They will learn to pay attention to the instructions of the audience, to use visual aids and to use clear and correct language. They should also be able to discuss the content of their presentation.
3	**Inhalte**

	1. This course provides an essential overview on approaches, methods and techniques of research planning and scientific writing. The goal of the course is providing students with an overview on research methodology and scientific writing sufficient for making qualified decisions regarding planning and writing a Master Thesis. What is research? How do we find an original topic? Data bases on the internet (SciFinder, Scopus, etc.). How to use a library? How do we plan a research project and how do we defend it? How do we apply for grants? Examples; Grant proposals. What is a Scientific Journal? What is the Science Citation Index and the Impact Factor of a journal? What is the structure of a scientific paper? What is the role of its sections? How should we write our paper and how do we submit it? 2. After an introduction to presentation techniques that contains essential aspects for writing presentation slides for a known audience, the students have to take care of the practical implementation. Starting with a task from the basics of physics or chemistry, a second phase will be a scientific presentation of a current topic from the field of nuclear applications. Essential aspects for writing and presenting are time management, the structure of the presentation and the techniques in speech and visualization. The presentation should contain all relevant points on the topic and a discussion about the origin of the data. Visual aids and their verbal and non-verbal presentation skills are discussed in the class and are intended to demonstrate interest and motivation in the field. At the end, the students should answer questions about the technical content of their presentation and then, in groups, discuss the advantages and disadvantages of their presentation techniques and should receive help for improvement.
4	**Lehrformen** 1. Lecture, Self-Study 2. Seminar, Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Written assignment (scientific paper, 6 - 12 pages) and presentation (20 min, includes preparation of slides, presentation of the topic, discussion with fellow students and lecturer and a handout summarizing the main points) 2. Presentations (30 - 45 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passing given assignments and presentations
8	**Verwendung des Moduls** (in anderen Studiengängen) none
9	**Stellenwert der Note für die Endnote** 4.17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Ziemons **Lehrende:** 1. Prof. Dr. Paulßen

	2. Prof. Dr. Ziemons
11	**Sonstige Informationen** more information for both courses are given on Ilias

Modul 5: Applied Data Analysis

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
310350	150 h	5	1. Sem.	Wintersemester	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	1. Introduction to Data Analysis with Matlab (310351) a) Lecture (1 SWS) b) Exercise (2 SWS) 2. Introduction to Monte Carlo Methods (310352) a) Lecture (1 SWS) b) Exercise (1 SWS)	5 SWS / 75 h	75 h	20

2 Lernergebnisse (learning outcomes) / Kompetenzen

1. The course is designed to provide students with a basic understanding of MATLAB, including suitable toolboxes for scientific purposes. The focus here is on "Learning by Doing". After the course, students are able to
   - read data,
   - perform data analysis, including required statistical approaches,
   - visualize data in a suitable scientific way.
2. The students repeat the mathematical methods used in simulations, in particular random walk methods. They get acquainted with practical MC calculations and know how to prepare input and run typical MC codes for radiation transport. They are able to interpret the output.
   The students will be able to implement their own MCNP calculation linked to a real detection situation that involves:
   - To build an input related to the specific situation
   - To run the code and obtaining results in an output file
   - To interpret the results in connection with theoretical background or comparison with real measurements

3 Inhalte

1. The course provides an introduction to the MATLAB computing environment and is aimed at students with little to no previous knowledge. It consists of interactive lectures and sample MATLAB problems given as assignments and discussed in class. Concepts cover basic use, graphical representations and tips for designing and implementing MATLAB code.
   Topics of the course content include:
   - access data from different file formats
   - use interactive tools for iterative exploration and visualization
   - design simple algorithms to solve problems
   - write simple programs in MATLAB to solve scientific and mathematical problems

	• know where to find help • automate and capture the work in easy-to-write scripts 2. Mathematical methods: Probability Theory, Random Number Generation, Random Sampling, Estimation of MC Errors, Variance Reduction Techniques. Application to typical MC codes of radiation transport.
4	**Lehrformen** Lecture, Exercise, and Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Written Assignment (appr. 10 pages) 2. The assignment is based on the creation of an MCNP input to simulate a specific gamma detection situation. The input has to be run on MCNP4C2 and the students have to write a report (10 pages) containing the following items: • small presentation of MCNP and the interest of the code for such exercice • explaination of the input file • analysis of the results with a special care for statistical tests
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed assignment
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4.17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Ziemons **Lehrende:** 1. Prof. Dr. Ziemons 2. Dr. Gerardy, Dr. Van den Cruyce
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. MATLAB documentation at https://www.mathworks.com/help/matlab/learn_matlab/data-analysis.html 2. Handout provided for the class along with free software

Modul 6: Elective (Fundamentals of Chemistry, Cell Biology, or Anatomy)

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
320220	150 h	5	1. Sem.	Wintersemester	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	1. Fundamentals of Chemistry (320510) a) Lecture (2 SWS) b) Exercise (2 SWS) 2. Cell Biology (320530) a) Lecture (4 SWS) 3. Anatomy (320520) a) Lecture (4 SWS)	4 SWS / 60 h	90 h	20

2 Lernergebnisse (learning outcomes) / Kompetenzen

Students select one of the elective classes: Fundamentals of Chemistry, Cell Biology or Anatomy. They can improve their knowledge in these basic fields of science, which are required for a better understanding of the applications of nuclear principles in Science and Technology.

1. Fundamentals of Chemistry
   The students are acquainted with the basic concepts and methods of chemistry. They gain knowledge in the chemical nature of matter and fundamental types of chemical reactions in a qualitative and quantitative way. They can calculate equilibrium compositions of reaction mixtures and apply Le Chatelier's principle to improve chemical yields. They understand the role of pH and can calculate pH values of acids, bases, salt and buffer solutions. They understand the role of redox reactions in life sciences, for corrosion and for storage and supply of energy. As such they gain the basic competences to study biochemistry and cell biology as well as material science.
2. Cell Biology
   The main goal of this lecture course is for the students to understand the role of the (eukaryotic) cell as the fundamental unit of both structure and function in live. The molecular aspects of the four essential building blocks (nucleic acids, amino acids, lipids and sugars) and the respective polymers (such as DNA, proteins, membrane, saccharides) will be stressed out, as well as the interplay between such polymers. How organelles will be formed, and what is there role in the cell.
3. Anatomy
   Macro-anatomical and micro-anatomical basics of the most important human organs and pathological changes at specific diseases. Anatomical and morphologic basics for the understanding of following specialized courses, e.g. biomechanics, cardiovascular engineering, ergonomics or safety engineering. Anatomical understanding for the construction of medical devices and implants for rehabilitation or organ substitution. Learning to enable independently deepening and further training in the field of activity. Bringing the specific anatomical knowledge into the interdisciplinary working field of the biomedical technology for problem solving of clinical and industrial F&E projects. Position of anatomy within the disciplines of science and their mutual meaning. Social and economic meaning of pathologically changed anatomical structures

3 Inhalte

	1. Fundamentals of Chemistry Basic Concepts: Atoms, elements, the periodic table, compounds; Measurements and SI-units, the mole Chemical Reactions: Precipitations, reactions of acids and bases, redox reactions; Balanced chemical equations; Atomic structure and the periodic table: Orbital theory Chemical Bonding: Lewis Theory, Valence Bond Theory, Molecular Orbital Theory Structure of Molecules: VSEPR model, lattices Chemical Equilibrium: Law of Mass Action, Le Chatelier's principle, acids and bases, buffer solutions, solubility product, electrochemical series, Nernst equation, galvanic cells, electrolysis, Chemistry of the elements, separation and analysis techniques 2. Cell Biology An introductory course focusing on the molecular aspects of modern cell biology. Topics include relevant chemical aspects (catalytic kinetics, equilibrium constant, free enthalpy and free energy, ...), the nucleus, chromatin and genome, DNA replication and repair, the cell cycle, transcription, translation, the assembly of supramolecular structures, membrane structure and function, cell signaling, cytoskeleton and cell motility, and energy production in mitochondria and chloroplasts. Additionally, the most relevant cell biological techniques (such as PCR, Western Blot, ...) and fundamental experimental results will be covered as well. 3. Anatomy Macro-anatomical and micro-anatomical basics of the most important organs: skeleton; kidney, adrenal gland and excretory system; blood; digestive system; heart; brain and nervous system, sensory organs; arteries, venes and lymphatic vessels; skeletal muscles; lungs; sexual organs. References to the biomedical technology, artificial organs and diseases.
4	**Lehrformen** Lecture, Exercise, Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Written exam (90 min) 2. Written exam (90 min) and oral presentation (15 min) 3. Written exam (90 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed module exam
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragte:** Prof. Dr. Paulßen

	Lehrende: 1. Prof. Dr. Paulßen 2. Dr. Reimer 3. N.N.
11	**Sonstige Informationen** additional course information can be found on Ilias

Modul 7: Nuclear Chemistry

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
320180	150 h	5	2. Sem.	Sommersemester	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	Nuclear Chemistry a) Lecture (2 SWS) b) Practical Training (2 SWS)	4 SWS / 60 h	90 h	20 (12 for practical training)

2	**Lernergebnisse (learning outcomes) / Kompetenzen** The students get an overview of topics relevant to Nuclear Chemistry. They are familiar with natural sources, production and separation techniques, and the chemistry of radioactive nuclides and elements. They are aware of and can handle safety and specific chemical problems when working with open radioactive sources. They can describe and calculate the effect nuclear processes have on chemical compounds and reactions. The students can explain and use analytical methods that are used to identify and trace radioactive molecules or that use radiation to characterize non-radioactive molecules. They become familiar with chemical problems related to common nuclear applications, such as the nuclear fuel cycle, nuclear waste and nuclear medicine.
3	**Inhalte** Sources of radioactive isotopes and elements, Production of radionuclides, Separation techniques and radiochemistry, Analytical methods, Radiation/Hot-atom chemistry, Tracer Techniques, Radiopharmaceuticals, Chemistry of the Actinides, Nuclear Fuel Cycle, Nuclear Waste, Transactinide Chemistry
4	**Lehrformen** Lecture, Practical Training, Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: The students should have a fundamental understanding of chemistry. This can be achieved by attending the elective course "Fundamentals of Chemistry".

6	**Prüfungsformen** Written exam (120 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** passed practical training, a report for each experiment needs to be handed in passed module exam
8	**Verwendung des Moduls** (in anderen Studiengängen) none
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** Prof. Dr. Paulßen
11	**Sonstige Informationen** additional course information can be found on Ilias

Modul 8: Nuclear Physics

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
310210	150 h	5	2. Sem.	Sommersemester	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	Nuclear Physics a) Lecture (2 SWS) b) Exercise (2 SWS)	4 SWS / 60 h	90 h	20

2	**Lernergebnisse (learning outcomes) / Kompetenzen** In this course, students learn basic principles of nuclear physics. They understand in a quantitative way the atomic nucleus, its constituents, and the nuclear forces. The can perform calculations of nuclear potentials and energy levels and predict nuclear stability/instability based on applications of nuclear models. Students can use the chart of the nuclides as a data resource. They are capable of calculating the energies of nuclear transformations and predict the outcome of nuclear decay and nuclear reactions in a quantitative way.
3	**Inhalte** This course contains: • Basics principles of Nuclear Physics (like models of the atom, the nucleus and its constituents, isotopes, isotones, masses) • Quantum mechanical basics (like e.g. spin, parity, magnetic moments) • Nuclear forces and models of a nucleus (like the Fermi gas model, independent particle model, shell model, collective model, modern theories)

	• Radioactive decay and weak decay models and calculations (like Gamow-Teller and Fermi transitions) • Kinematics and nuclear reactions (like elastic and inelastic scattering, transfer reactions, resonances, virtual states, compound reactions, optical model)
4	**Lehrformen** Lecture, Exercise, Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** Written exam (90 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed module exam
8	**Verwendung des Moduls** (in anderen Studiengängen) none
9	**Stellenwert der Note für die Endnote** 4.17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** Prof. Dr. Langer
11	**Sonstige Informationen** **Literatur und Lernunterlagen** additional course information can be found on ILIAS

Modul 9: Nuclear Applications 1

Kennnummer	**Workload**	**Credits**	**Studiensemester**	**Häufigkeit des Angebots**	**Dauer**
320050	150 h	5	2. Sem.	Sommersemester	1 Semester

	Lehrveranstaltungen	**Kontaktzeit**	**Selbststudium**	**geplante Gruppengröße**
1	1. Nuclear Data for Science and Technology (320110) a) Lecture (2 SWS) 2. Reactor Physics (320140)	4 SWS / 60 h	90 h	20

	a) Lecture (2 SWS)			
2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. In this course the students receive a fundamental insight in the role of nuclear data in several areas. They learn which physical and radiochemical methods are used for data acquisition in practice and can apply fundamental methods of calculation. They can assess evaluated data by using the underlying theories, systematics and fitting procedures. They can work with data files, libraries and data banks. The students can identify, describe, interpret and use nuclear data for energy and non-energy related applications. 2. The students learn the fundamentals of the applied nuclear physics and understand to describe the mechanism of neutron production by fission, moderation, diffusion and multiplication as well as the resulting chain reaction. In addition, the course is intended to transfer the fundamentals of the transport and diffusion theory as well as the statistical methods to the students for reactor physics calculations. Furthermore, they can apply the reactor physics methods to the design issues and nuclear engineering aspects of nuclear reactors. Moreover, they learn the mechanism of the fuel depletion, burnup and transmutation including the theoretical background and calculation methods. Based on the material balance equations the course covers also the radiological characterization of the radioactive material and high-level waste generated during the operation of a nuclear power plant.			
3	**Inhalte** 1. General introduction to nuclear data, experimental techniques used for data determination, physical methods, radiochemical methods, theoretical calculation of nuclear data, evaluation of data using theory and fitting procedures, systematics of data, data files and libraries, data banks, applications of nuclear data in fission, fusion and ADS systems, applications of nuclear data in medicine, technology and other fields. 2. The reactor physics course covers following topics: Fundamentals of applied nuclear physics, Neutron reaction with matter, The concept of neutron cross section (Neutron scattering and thermalization, Process of absorption, fission and activation), The Neutron life-generation and cycle, Neutron multiplication and stable chain reaction, Fick's law with neutron Flux & Current, Neutron diffusion and balance Equation, Neutron flux and fission power distribution in a reactor, Main reactor physics aspects of a nuclear reactor design, Nuclear fuel burnup and depletion, Material activation and radioactivity, Physics of a time dependent nuclear reactor			
4	**Lehrformen** 1. Lecture including Exercises and Self-Study 2. Lecture, Self-Study			
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: 1. Basic knowledge of chemistry/physics/engineering 2. None			
6	**Prüfungsformen** 1. Written exam (90 min) 2. Written exam (120 min)			
7	**Voraussetzungen für die Vergabe von Kreditpunkten**			

	Passing the exams of both lectures
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Langer **Lehrende:** 1. Prof. Dr. Dr. h.c. mult. Qaim 2. Prof. Dr. Nabbi
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. Handout, Review articles 2. Lecture notes and script John R. Lamarsh & Anthony J. Baratta, "Introduction to Nuclear Engineering" PEARSON comp.; 4th edition, 2017, ISBN-10: 0134570057 M. Stacey, Nuclear Reactor Physics, Wiley Interscience 2001, ISBN 0471391271

Modul 10: Nuclear Applications 2

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
320060	150 h	5	2. Sem.	Sommersemester	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	1. Biomedical Applications (320120) a) Lecture (2 SWS) 2. Radioecology (320130) a) Lecture (2 SWS)	4 SWS / 60 h	90 h	20

2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. The students get an overview of principles and design concepts to nuclear applications in medicine and biology for healthcare purposes (e.g. diagnostic or therapeutic). a. For diagnostics they understand the essential principles of operation of magnetic resonance (MRI), diagnostic imaging techniques (PET and SPECT) in nuclear medicine, in-vivo and in-vitro autoradiography. They are able to differentiate the imaging modalities, and can describe their fundamental promises and limitations. b. By using the different kinds of transport mechanism in a living system they can explain the bio-distribution from the kinetic process of reaction.

	c. Students get functional and methodical based competences and gain insights into the image analysis tools d. They have theoretical knowledge about radionuclide and radiation therapy 2. Students understand the origin of natural and artificial radionuclides. By integrating the radiation biology and the nuclear decay properties they acquire a fundamental understanding of the influence of environmental radioactivity on human health. They know the fundamental design of radioecological models. By using examples of human exposure to natural radiation sources (indoor radon) and artificial radiation (different cases of accidents) they can explain the estimation of risks and remedial actions to be taken. They can apply these principles to preventive interaction e.g. for the case of the design of repositories. Students know special techniques for the measurement of environmental radioactivity, especially radon.
3	**Inhalte** 1. Nuclear applications in medicine and biology: • tracer applications and kinetic modelling • in-vivo and in-vitro autoradiography • essential principles of operation of magnetic resonance (MRI), • diagnostics in nuclear medicine imaging and metabolism • radionuclide therapy • introduction to radiation therapy • plant physiology • food irradiations and sterilization techniques 2. Natural radioactivity: primordial and cosmogenic radionuclides; Anthropogenic alterations of the natural inventories; Anthropogenic radionuclides; Radiological consequences; Radiometrical and Radiochemical measurements; Nuclear Waste Management.
4	**Lehrformen** Lecture, Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Written exam (90 min) 2. Written exam (90 min, 70% of the grade) and group presentation with slides (30 min, 30% of the grade) (alternatively: individual presentation 10 minutes) For the presentation: slides and individual performance are graded, as well as participation to the discussion afterwards.
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passing the exams of both lectures
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende**

	Modulbeauftragter: Prof. Dr. Ziemons **Lehrende:** 1. Prof. Dr. Ziemons 2. Prof. Dr. Steinmetz
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. J. Lilley, Nuclear Physics - Principles and Application, J. Wiley, Chichester, 2002, ISBN 0-471-97936-8 G.Choppin, J.-O. Liljenzin, J. Rydberg, Radiochemistry and Nuclear Chemistry, Butter-worth Heinemann, 3rd ed., 2000, ISBN 0-7506-7463-6. Lecture slides will be made available to the students 2. G.Choppin, J.-O. Liljenzin, J. Rydberg, Radiochemistry and Nuclear Chemistry, Butter-worth Heinemann, 3rd ed., 2000, ISBN 0-7506-7463-6

Modul 11: Scientific Skills

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
330050	150 h	5	3. Sem.	Wintersemester	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	1. Ethics of Nuclear Risk Governance (330120) a) Seminar (2 SWS) 2. Research Seminar (330130) a) Seminar (2 SWS)	4 SWS / 60 h	90 h	20

2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. The students develop an understanding for ethical reasoning and judgment of technology. 2. Students can discuss the reports of others in a balanced manner and gain an overview of current research and development tasks at universities, research laboratories or in industry. This often leads to initial contacts with potential supervisors of a master's thesis outside the university.
3	**Inhalte** 1. *Introduction:* Due to the specific character of its associated risk, the societal justification of nuclear energy technology is troubled by moral pluralism. That is: even if we would all agree on the scientific knowledge base for the assessment of the risk, opinions could still differ on its acceptability. Science may thus inform us about the technical and societal aspects of options, it cannot instruct or clarify the choice to make. The matter becomes even more complex if we take into account the fact that science can only deliver evidence to a certain extent. Despite the maturity of nuclear science & engineering, the existence of inherent uncertainties, unknowns and unknowables puts fundamental limits

	to understanding and forecasting technological, biological and social phenomena in the interest of risk assessment. Last but not least, we have to accept that important factors remain to a large degree beyond control. These are human behaviour, nature, time and misuse of technology… The resulting room for interpretation that unavoidably marks any 'political act of justification' puts a heavy responsibility on nuclear technology assessment as a research and policy practice. The lecture will focus on the science, politics and ethics of nuclear technology assessment by starting from an analysis of the complexity of nuclear risk governance and by linking these insights to the question of how approaches to science as policy advise and political decision making could 'generate societal trust'. The idea is that this trust would need to be generated 'by method instead of proof', regardless of whether the outcome of decision making would be acceptance or rejection of the technology. Consequently, it will propose to understand energy governance as a 'complex social problem' with risk as its central concern, and suggest a specific ethical vision on energy governance and the practical implications thereof for research and policy. *Objectives:* The overall aim of the seminar is to provide better insight into the complexity of (nuclear) energy governance and to discuss as well the moral foundations for risk governance as the practical implications for research and policy. Consequently, the seminar participants should be able to better evaluate the politics of current (nuclear) energy policy practices (in particular with respect to the working of science as policy advice) and to develop an own critical opinion with respect to the political and ethical aspects of nuclear energy governance in particular and of energy governance in general. 2. Invited speakers from the field of nuclear applications from science or industry present their current research activities and developments. The students discuss with them the content of the presentation and possible aspects in the application.
4	**Lehrformen** Seminar, Self Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Tests about each topic (10 - 20 min) 2. Written Assignment (maximum 2 pages A4 including tables or figures)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed assignments
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Ziemons **Lehrende:**

	1. Dr. Meskens 2. Prof. Dr. Ziemons
11	**Sonstige Informationen** **Literatur und Lernunterlagen** Handouts and literature

Modul 12: Modelling and Simulation

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
330060	150 h	5	3. Sem.	Wintersemester	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	Modelling and Simulation a) Lecture (2 SWS) b) Exercise (1 SWS) c) Practical Training (1 SWS)	4 SWS / 60 h	90 h	20

2	**Lernergebnisse (learning outcomes) / Kompetenzen** Advanced computing and computer simulation using numerical methods allow research institutes, industry as well as the universities to realize technological innovation and new developments in nuclear technology and nuclear applications in particular. The students design and utilize computational and simulation methods and software programs for nuclear engineering and applications (applicable to nucl. reactors, rad-waste characterization as well as charged particle and gamma ray applications). The students know principles of nuclear and radiation physics, can describe concepts of numerical methods, and can apply modelling and simulation techniques. They simulate nuclear process and radiation transport using advanced numerical tools. In particular the deterministic as well as the stochastic Monte-Carlo methods are imparted and applied for nuclear and radiation engineering problems.
3	**Inhalte** In particular, following aspects will be covered: 1. Fundamentals of numerical methods and modeling techniques • Analytical Methods and deterministic (numerical) Method • Conservation laws, Balance equations, Eigenvalue problems, • The method of finite differences • Runge-Kutta Method of numerical integration 2. Math. and numerical background of the Monte-Carlo method • Fundamentals of the statistics • Models for stochastic nuclear processes • Random number and Probability distribution and convergency 3. Numerical methods for selected nucl. applications • Neutron multiplication and steady state reactor physics • Neutron kinetics and reactor time behavior(dynamics)

	• Fuel depletion, Activation, radio-isotope generation • Neutron and radiation transport and Shielding 4. Code applications: Simulation of selected nucl. engineering problems • Nuclear reactor: Simulation of fission process, neutron interactions and chain reaction (DIFF-2D code) • Numerical simulation of neutron kinetics and time dependent behavior (SOTRAN code) • Simulation of fuel depletion with the formation of actinides und fission products (SUSAN/ORIGEN Code) • Simulation of radiation-matter interaction(with the Radiation shielding code RAD-DOSE) • Heat transfer and mass flow simulation using the HEATHYD code • Application of Monte-Carlo-technique and code for Photon and particle transport simulation (Basic applications: SRIM/ MCNP)
4	**Lehrformen** Lecture, Exercise, Practical Training, Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** Written exam (120 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passing the module exam and the practical training
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** Prof. Dr. Nabbi
11	**Sonstige Informationen** **Literatur und Lernunterlagen** • Lecture notes and script • G. E. Sjoden, Foundations in Applied Nuclear Engineering Analysis, World Scientific • Publishing Co. Pte. Ltd,2009 • E. E. Lewis: Computational methods of neutron transport. Wiley-Inter-science, 1993 • G. Croff, ORIGEN2.2. Isotope Generation and Depletion Code Matrix Exponential Method, • Oak Ridge National Laboratory, 2002. • G. S. Fishman, Monte Carlo: Concepts, Algorithms and applications: Springer-Verlag, New York, 1996. • J. J. Duderstadt; L. J. Hamilton: Nuclear Reactor Analysis. John Wiley & Sons, 1976

	• Dan G. Cacuci: Handbook of Nuclear Engineering, Springer Science & Business Media 2010, LLC

Modul 13: Project Nuclear Applications

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
320300	300 h	10	3. Sem.	Winter and summer semester	1 Semester

1	**Lehrveranstaltungen** Project Nuclear Applications	**Kontaktzeit** -	**Selbststudium** 300 h	**geplante Gruppengröße**
2	**Lernergebnisse (learning outcomes) / Kompetenzen** Application of nuclear principles to ongoing research projects. The students develop their scientific and writing skills.			
3	**Inhalte** The students work on a defined project in the framework of on-going research projects in-house or with collaborating institutions.			
4	**Lehrformen** Self-study			
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: Students should contact professors that teach courses in the Master of Nuclear Applications about possible projects. Alternatively, they can discuss with them, which external projects are suited for their study program. The project needs to be supervised by a professor of the FH Aachen.			
6	**Prüfungsformen** Written report (20 - 30 pages)			
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed report			
8	**Verwendung des Moduls** (in anderen Studiengängen) None			
9	**Stellenwert der Note für die Endnote** 8,33 %			
10	**Modulbeauftragte/r und hauptamtlich Lehrende**			

	Modulbeauftragter: Prof. Dr. Paulßen **Lehrende:** all supervising professors
11	**Sonstige Informationen**

Vertiefungsfächer (Focus Fields)

Die Studierenden spezialisieren sich in einer der vier Vertiefungsrichtungen

- Nuclear Power
- Medical Physics
- Nuclear Chemistry
- Nuclear Waste Management

Module von mindestens 15 ECTS (von insgesamt 20 ECTS) müssen aus dem jeweiligen Angebot einer der vier Vertiefungsrichtungen ausgewählt werden. Bis zu weitere 5 ECTS können aus dem Kursangebot der anderen Vertiefungsrichtungen oder der anderen englischsprachigen Masterprogramme (z.B. Master Medizintechnik an der FH Aachen) auf Anfrage angerechnet werden. Die Studierenden werden angehalten, an dem Angebot des europäischen Hochschulnetzwerks CHERNE teilzunehmen. Dort erworbene Leistungspunkte können angerechnet werden.

Students specialize in one of four focus fields Nuclear Power, Medical Physics, Nuclear Chemistry or Nuclear Waste Management. Modules of min. 15 ECTS (of total 20 ECTS) have to be selected from the proposed lists. Up to 5 ECTS can be selected from other focus fields or from other master programs (e.g. Master Medizintechnik at the FH Aachen) by appointment. We encourage students to participate in courses organized by the European University Network CHERNE. Credits earned in these courses will be recognized.

Modul-Nr.	Modul	LP	Nuclear Technology	Medical Physics	Nuclear Chemistry	Nuclear Waste Management	dem Modul zugeordnete Lehrveranstaltungen
335300	Advanced Radiochemical and Radioanalytical Methods	5			◇		1. Advanced Radiochemical Methods (P2S1) 2. Environmental Radiation Detection (P2)
335310	Applications of Accelerators and Dosimetry	5	◇		◇		1. Applications of Accelerators (V2) 2. Dosimetry of Incorporated Radionuclides (V2)
335320	Applications of Accelerators and Waste Management	5		◇			1. Applications of Accelerators (V2) 2. Nuclear Waste Management (V2S1)
335330	Decommissioning and Waste Management	5	◇		◇		1. Decommissioning (V2) 2. Nuclear Waste Management (V2S1)
	Dosimetry and Radiation Therapy	5		◇			1. Dosimetry of Incorporated Radionuclides (V2) 2. Radiation Therapy (V2P1)
	Entsorgungsstrategien in Deutschland [1]	5				◇	1. Rechtliche Aspekte in Handhabung, Transport und Lagerung radioaktiver Abfälle (V2) 2. Zwischenlagerung und deutsche Endlagerkonzepte (V2)
	Fuel and Waste Technology	5	◇				1. Nuclear Fuels (V2) 2. Nuclear Waste Technology (V2S1)
	Fundamentals in Nuclear Waste Management	5				◇	1. Nuclear Waste Management (V2S1)

[1] This module will only be offered in German.

							2. Waste Management Concepts (S2)
	Materials in Nuclear Waste Management	5			◇	◇	1. Ageing Phenomena in Nuclear Materials (V2) 2. Ageing Management (V2)
335340	Nuclear Fuels and Actinide Chemistry	5			◇		1. Nuclear Fuels (V2) 2. Actinide Chemistry (V2)
	Nuclear Medicine and Imaging	5		◇			1. Nuclear Medicine (V2) 2. Nuclear Imaging (V2)
335110	Nuclear Power Generation and Nuclear Materials	5	◇				1. Nuclear Power Generation and Nuclear Materials (V4)
335370	Nuclear Technology Lab	5	◇				1. Reactor Lab (P2) 2. Environmental Radiation Detection (P2)
335400	Radionuclide Production and Radiopharmacy	5		◇	◇		1. Radionuclide Production (V2) 2. Labeling and Radiopharmaceutical Chemistry (V2)
335390	Strahlenschutzkurs für Medizinphysiker [2]	5		◇			1. Strahlenschutzkurs für Medizinphysiker (V3P1)
	Waste Products and Waste Packages	5				◇	1. Decommissioning (V2) 2. Nuclear Waste Technology (V2S1)

[2] This module will only be offered in German.

Advanced Radiochemical and Radioanalytical Methods

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
335300	150 h	5	2./3. Sem.	once a year	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	1. Advanced Radiochemical Methods (335020) Practical Training a) Practical Training (2 SWS) b) Seminar (1 SWS) 2. Environmental Radiation Detection (335060) a) Practical Training (2 SWS)	5 SWS / 75 h	75 h	6

2 Lernergebnisse (learning outcomes) / Kompetenzen

1. Based on their previous practical experiences and research papers the students can organize complex radiochemical and radioanalytical procedures. They can assess specific tasks required, plan and arrange the specific radiochemical and detection methods to fulfil a given task. The perform the analytical calculations including the estimate of uncertainties and report the results including a detailed evaluation of the data.
2. The students recognise the required methods of radiation detection for environmental radionuclides. They select appropriate methods for the practical solution of the task including appropriate sample treatment and chemical separation and perform measurements. They use alternative methods of measurement and calculation of the data including the analysis of the measurement uncertainties. They report their results in common standard formats and discuss the relevance of the results.
   The students understand the analytical use of X-rays and can explain the different methods. They are able to perform different types of X-ray Fluorescence Analysis.

3 Inhalte

1. The students work on small projects that are based on research papers using typical radiochemical techniques. Examples are: radiochemical separations, separation at no-carrier-added level, solvent extraction, ion-exchange chromatography, distillation and thermochromatography, radiolabelling procedures, principles of radionuclide generators
2. Samples will be collected from the environment, chemically treated and measured to determine their radionuclide content.

4 Lehrformen

Practical Training, Self-Study

5 Teilnahmevoraussetzungen

formal conditions: none

information on preparation: For Advanced Radiochemical Methods students should have an in-depth theoretical and practical knowledge of chemistry. This course is intended for students who do have a bachelor degree in chemistry.

6 Prüfungsformen

	Reports (10 - 20 pages) and presentations (20 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed reports
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** Prof. Dr. Paulßen
11	**Sonstige Informationen** **Literatur und Lernunterlagen** Materials are available on Ilias.

Applications of Accelerators and Dosimetry

Kennnummer	**Workload**	**Credits**	**Studiensemester**	**Häufigkeit des Angebots**	**Dauer**
335310	150 h	5	2./3. Sem.	once a year	1 Semester

	Lehrveranstaltungen	**Kontaktzeit**	**Selbststudium**	**geplante Gruppengröße**
1	1. Application of Accelerators (335030) a) Lecture (2 SWS) 2. Dosimetry of incorporated radionuclides (335050) a) Lecture (2 SWS)	4 SWS / 60 h	90 h	20

2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. The students understand the basic principles of particle accelerators. They recognize the relevance of particle accelerators in various fields of research and application. To reach this goal, the students identify and characterize the relevant properties of accelerated charged particles and how they are applied. They understand the differences between various acceleration strategies and can summarize advantages and disadvantages of those techniques. 2. Incorporated radionuclides play an increasing role in diagnostic and therapeutic nuclear medicine as well as in the public concern due to possible accidental releases or terrorist threats. Due to this relevance, the students will recognize the implications of different radiation emission spectra of radionuclides inducing characteristic energy deposition patterns on the molecular, cellular and organ level of living species; moreover, they will

	analyze the problems associated with corresponding dosimetric approaches, and get acquainted with the basics of modern computational methods in the field (Monte Carlo simulation of track structures, modeling of biological target structures).
3	**Inhalte** 1. This course contains: a. Basic principles b. Ion sources c. Accelerator types (static and dynamic, ions and electrons, neutron generators, radiation sources) d. Accelerator-based research (like production of radionuclides, fundamental research, Accelerator-Mass-Spectrometry, Activation) e. Accelerator-based applications (like Food Irradiation & Sterilization, Medical irradiations, analytical applications: PIGE, PIXE, ERDA, RBS, NRA; Material Science) f. Partitioning and Transmutation of Radionuclides relevant in medicine and radioecology 2. Radionuclides relevant in medicine and radioecology; Decay modes, emission spectra and particle ranges; Interaction of radiation with matter: Track structures, low- and high-LET; Biological targets, DNA configurations; Energy deposition patterns on the molecular, cellular and organ level; Dosimetry vs. Microdosimetry; Radiation biophysics: from primary physical events to biological endpoints, experimental findings and computer simulation; Dosimetry in nuclear medicine and radiation protection: MIRD, ICRP; Modern computational methods (MC Auger electron emission spectra, track structures, MCNP); Quantities and Units
4	**Lehrformen** Lecture, Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Written exam (90 min) or oral exam (30-40 min), depending on the number of students 2. Written exam (90 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed module exams
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Ziemons **Lehrende:** 1. Dr. Sanjari 2. Dr. Pomplun

11	Sonstige Informationen
	Literatur und Lernunterlagen 1. Information can be found on Ilias 2. J.E. Turner: Atoms, Radiation, and Radiation Protection, WILEY-VCH J. Kiefer: Biological Radiation Effects, Springer

Applications of Accelerators and Waste Management

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
335320	150 h	5	2./3. Sem.	once a year	1 Semester

1	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
	1. Application of Accelerators (335030) a) Lecture (2 SWS) 2. Nuclear Waste Management (335120) a) Lecture (2 SWS) b) Seminar (1 SWS)	5 SWS / 75 h	75 h	20

2	Lernergebnisse (learning outcomes) / Kompetenzen
	1. The students understand the basic principles of particle accelerators. They recognize the relevance of particle accelerators in various fields of research and application. To reach this goal, the students identify and characterize the relevant properties of accelerated charged particles and how they are applied. They understand the differences between various acceleration strategies and can summarize advantages and disadvantages of those techniques. 2. Students have all relevant knowledge of international and national legal standards with regard to predisposal and disposal of radioactive waste, in particular competences in the field of approval procedures. The students acquire in-depth knowledge in the classification and radiological evaluation of the various waste streams as well as in the relevant disposal paths and technologies. They know about relations and interdependencies in the thematic area of Nuclear Waste Management and are capable to apply this knowledge. In particular they are able to understand and to consider waste management concepts.
3	**Inhalte**
	1. This course contains: a. Basic principles b. Ion sources c. Accelerator types (static and dynamic, ions and electrons, neutron generators, radiation sources) d. Accelerator-based research (like production of radionuclides, fundamental research, Accelerator-Mass-Spectrometry, Activation) e. Accelerator-based applications (like Food Irradiation & Sterilization, Medical irradiations, analytical applications: PIGE, PIXE, ERDA, RBS, NRA; Material Science) f. Partitioning and Transmutation of Radionuclides relevant in medicine and radioecology

	2. This course imparts basics and fundamental knowledge about the topic field of nuclear waste management. Specialists information, application-oriented knowledge and competences (subjects and methods) are provided or trained in the separate course "Waste Disposal Concepts". Disposal is the final step of the life cycle of nuclear waste including used nuclear fuel declared as waste. Before final disposal, the nuclear waste usually goes through a number of steps such as pre-treatment, treatment, conditioning, storage and transport with characterization utilized within the entire cycle of radioactive waste. The safe management and storage of nuclear waste and used nuclear fuel depends largely upon the utilization of nuclear waste predisposal technologies. Predisposal management encompasses all steps that collectively cover the activities from waste generation up to final disposal, ending with interim storage, clearance or recycling. In this lecture all important steps within the generic disposal chain for radioactive waste are addressed and described, including the final or interim endpoints. The students get to know the most important organizational, technical and legal constraints and dependencies which have to be considered in predisposal management. The students will know about the radioactive waste classification systems worldwide, as well as the most important waste streams, including steps and options in their individual life cycle (operational waste from nuclear power generation, decommissioning waste, institutional waste as well as legacy waste).
4	**Lehrformen** 1. Lecture and Self-Study 2. Lecture and Seminar and Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Written exam (90 min) or oral exam (30-40 min), depending on the number of students 2. Written exam (90 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed module exams
8	**Verwendung des Moduls** (in anderen Studiengängen) **None**
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Langer **Lehrende:** 1. Dr. Sanjari 2. Prof. Dr. Steinmetz, Prof. Dr. Ojovan (Imperial College London, UK)
11	**Sonstige Informationen** **Literatur und Lernunterlagen**

	1. Information can be found on Ilias 2. Handout, Review articles Lecture notes and script John R. Lamarsh & Anthony J. Baratta, "Introduction to Nuclear Engineering" PEARSON comp.; 4th edition, 2017, ISBN-10: 0134570057 M. Stacey, Nuclear Reactor Physics, Wiley Interscience 2001, ISBN 0471391271

Decommissioning and Waste Management

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
335330	150 h	5	2./3. Sem.	once a year	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	1. Decommissioning (335040) a) Lecture (2 SWS) 2. Nuclear Waste Management (335120) a) Lecture (2 SWS) b) Seminar (1 SWS)	5 SWS / 75 h	75 h	20

2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. The students assess methods to dismantle and decontaminate plants. They realize the steps to a "Green field site" and the meaning of the different periods. They illustrate essential separation and disassembly techniques as well as decontamination technologies suitable for decommissioning. They exemplify by previous and recent decommissioning projects at the site. They are able to integrate the various procedures and propose generalized approaches. The students learn about the main problems and solutions with regard to radiation protection during decommissioning. They know the essential methods which can be used for the clearance measurement of buildings. They can distinguish the different ways of a dismantled component which lead to disposal or clearance measurement. 2. Students have all relevant knowledge of international and national legal standards with regard to predisposal and disposal of radioactive waste, in particular competences in the field of approval procedures. The students acquire in-depth knowledge in the classification and radiological evaluation of the various waste streams as well as in the relevant disposal paths and technologies. They know about relations and interdependencies in the thematic area of Nuclear Waste Management and are capable to apply this knowledge. In particular they are able to understand and to consider waste management concepts.
3	**Inhalte** 1. Inventories: measurement methods, dismantling; decontamination; legal requirements • From the final shut down until the first step of decommissioning • Separation and disassembly techniques and equipment for the dismantling of nuclear installations – including legal requirements • Decontamination technologies • Radiation protection during decommissioning • Clearance measurement of buildings

	• Waste management, disposal and clearance measurement of components 2. This course imparts basics and fundamental knowledge about the topic field of nuclear waste management. Specialists information, application-oriented knowledge and competences (subjects and methods) are provided or trained in the separate course “Waste Disposal Concepts”. Disposal is the final step of the life cycle of nuclear waste including used nuclear fuel declared as waste. Before final disposal, the nuclear waste usually goes through a number of steps such as pre-treatment, treatment, conditioning, storage and transport with characterization utilized within the entire cycle of radioactive waste. The safe management and storage of nuclear waste and used nuclear fuel depends largely upon the utilization of nuclear waste predisposal technologies. Predisposal management encompasses all steps that collectively cover the activities from waste generation up to final disposal, ending with interim storage, clearance or recycling. In this lecture all important steps within the generic disposal chain for radioactive waste are addressed and described, including the final or interim endpoints. The students get to know the most important organizational, technical and legal constraints and dependencies which have to be considered in predisposal management. The students will know about the radioactive waste classification systems worldwide, as well as the most important waste streams, including steps and options in their individual life cycle (operational waste from nuclear power generation, decommissioning waste, institutional waste as well as legacy waste).
4	**Lehrformen** 1. Lecture and Self-Study 2. Lecture, Seminar and Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Written exam (90 min) 2. Written exam (90 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed module exams
8	**Verwendung des Moduls** (in anderen Studiengängen) **None**
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Langer **Lehrende:** 1. Burkhard Stahn (Leiter Rückbauprojekte, JEN) 2. Prof. Dr. Steinmetz, Prof. Dr. Ojovan (Imperial College London, UK)
11	**Sonstige Informationen**

	Literatur und Lernunterlagen 1. Transition from Operation to Decommissiong of Nuclear Installations, IAEA, 2004; C.R. Bayliss, K.F. Langley: Nuclear Decommissioning, Waste Management, and Environmental Site Remediation, Butterworth-Heinemann, 2003 Chang Ho Oh (ed.) Hazardous and Radioactive Waste Treatment Technologies Handbook, CRC Press, 2001, ISBN 0849395860 2. Handout, Review articles Lecture notes and script John R. Lamarsh & Anthony J. Baratta, “Introduction to Nuclear Engineering” PEARSON comp.; 4th edition, 2017, ISBN-10: 0134570057 M. Stacey, Nuclear Reactor Physics, Wiley Interscience 2001, ISBN 0471391271

Dosimetry and Radiation Therapy

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
	150 h	5	2./3. Sem.	once a year	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	1. Dosimetry of incorporated radionuclides (335050) a) Lecture (2 SWS) 2. Radiation Therapy a) Lecture (2 SWS) b) Practical Training (1 SWS)	5 SWS / 75 h	75 h	20

2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. Incorporated radionuclides play an increasing role in diagnostic and therapeutic nuclear medicine as well as in the public concern due to possible accidental releases or terrorist threats. Due to this relevance, the students will recognize the implications of different radiation emission spectra of radionuclides inducing characteristic energy deposition patterns on the molecular, cellular and organ level of living species; moreover, they will analyze the problems associated with corresponding dosimetric approaches, and get acquainted with the basics of modern computational methods in the field (Monte Carlo simulation of track structures, modeling of biological target structures). 2. The students recognize the workflow of a radiation therapy treatment and have an overview over the different therapy possibilities and concepts. They are able to make simple radiobiological calculations and simple dose calculations. They know different quality assurance measurements and their measurement equipment.
3	**Inhalte** 1. Radionuclides relevant in medicine and radioecology; Decay modes, emission spectra and particle ranges; Interaction of radiation with matter: Track structures, low- and high-LET; Biological targets, DNA configurations; Energy deposition patterns on the molecular, cellular and organ level; Dosimetry vs. Microdosimetry; Radiation biophysics: from primary physical events to biological endpoints, experimental findings and computer simulation; Dosimetry in nuclear medicine and radiation protection: MIRD, ICRP;

	Modern computational methods (MC Auger electron emission spectra, track structures, MCNP); Quantities and Units 2. Topics Radiation Therapy (RT): workflow of a RT treatment, imaging modalities and their use for the RT treatment planning, treatment concepts (curative, palliative), radio-biology focusing on RT, RT treatment planning (2D, 3D-conformal, IMRT, VMAT), treat-ment planning algorithms, special irradiation techniques: STX, IGRT, ART, IORT, Brachytherapy, Proton- and Particle Therapy, RT quality assurance
4	**Lehrformen** 1. Lecture and Self-Study 2. Lecture, Practical Training and Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Written exam (90 min) 2. Written exam (90 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed module exams
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Ziemons **Lehrende:** 1. Dr. Pomplun 2. Dr. Kathrin Gester, Dr. Gisela Hürtgen
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. J.E. Turner: Atoms, Radiation, and Radiation Protection, WILEY-VCH J. Kiefer: Biological Radiation Effects, Springer 2. available on Ilias

Entsorgungsstrategien in Deutschland[3]

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
	150 h	5	2./3. Sem.	once a year	1 Semester

1	**Lehrveranstaltungen** 1. Rechtliche Aspekte in Handhabung, Transport und Lagerung radioaktiver Abfälle a) Lecture (2 SWS) 2. Zwischenlagerung und deutsche Endlagerkonzepte a) Lecture (2 SWS)	**Kontaktzeit** 4 SWS / 60 h	**Selbststudium** 90 h	**geplante Gruppengröße** 20
2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. Die Studierenden werden in das Lesen, Verstehen und die praktische Anwendung einschlägiger Rechtsnormen eingeführt. Sie kennen alle relevanten internationalen und nationalen Rechtsnormen sowie technischen Vorschriften zu Transport, Lagerung und Entsorgung radioaktiver Abfälle. Sie kennen die nationale Organisation des kerntechnischen Betriebs- und Aufsichtswesens. Sie kennen die Akteure und Zuständigkeiten der beteiligten Parteien (Betreiber, Aufsichtsbehörden, Sachverständige, unabhängige Gutachter) sowie die Rechte der Öffentlichkeit innerhalb eines atomrechtlichen Genehmigungsverfahrens. Sie sind mit dem Prozess des Standortauswahlverfahrens für hochradioaktive Abfälle vertraut und kennen Möglichkeiten der Öffentlichkeitsbeteiligung. 2. Die Studierenden sind mit den baulichen und betrieblichen Anforderungen an Zwischenlager vertraut. Sie kennen die technischen Anforderungen an Transport- und Lagerbehälter sowie Schutz- und Sicherheitskonzepte für standortinterne und öffentliche Transporte radioaktiver Stoffe. Sie verstehen den gesamten Prozess der Endlagerung von der Genehmigung über den Betrieb bis zum Verschluss des Bergwerks sowie Sicherheitskonzepte in Abhängigkeit vom Wirtsgestein. Sie sind mit den Zwischenlager-sowie Einlagerungstechniken für das Endlager KONRAD vertraut und kennen die Anforderungen an Abfallprodukte.			
3	**Inhalte** 1. Schutzgüter, Schutzziele, Standortauswahlgesetz, Subsidiaritätsprinzip, EU-Vertrag, EURATOM-Vertrag, Grundgesetz, Atomgesetz, Gesetz zur Neuordnung der Verantwortung in der kerntechnischen Entsorgung, Strahlenschutzgesetz, Strahlenschutzverordnung, StandAG, Richtlinien 2011/70/EURATOM, 2013/59/EURATOM, Orange Book der UN, IAEA-SSR-6, ADR, RID, Gefahrgutbeförderungsgesetz, Gefahrgutverordnung Straße, Eisenbahn und Binnenschifffahrt, BMU-Kriterien (Phasenkonzept), KTA-Regeln, DIN-Normen, Leitlinien der ESK 2. Grundsätze der Behälterlagerung in Deutschland, Beispiele für Lagertypen in Deutschland, Konzept der dezentralen Zwischenlagerung in Deutschland, Übersicht – Zwischenlager (Designtypen, Infrastruktur), Störfallanalyse, Stresstests zur Bewertung der Anlagensicherheit, verkehrsrechtliche Zulassung, technische Annahmekriterien der Zwischenlager, Betriebsführung von Zwischenlagern gemäß Aufbewahrungsgenehmigung nach § 6 AtG, die wichtigsten Betriebsabläufe im Zwischenlager, Aspekte der Abfalllogistik (Verzahnung von Zwischenlagerung, Transport, Bereitstellungslagerung für die Endlagerung			

[3] This module will be only offered in German.

	und Endlager-Einlagerungsbetrieb), Sicherheitskonzept eines Endlagers, Anforderungen an die in das Endlager KONRAD endzulagernden Abfallgebinde resultierend aus der sicherheitsanalytischen Betrachtung, Endlagerbedingungen KONRAD.
4	**Lehrformen** Lecture, Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Presentation (30 min, depending on the number of participants also in small groups can include preparation of suitable slides, presentation of the topic, discussion with fellow students and lecturer and a handout summarizing the main points) 2. Written assignment (90 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed presentation and assignment
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Steinmetz **Lehrende:** 1. Kunigunde Beyer (BGZ) 2. Stefan Weber (BGZ)
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. s.o. unter Inhalte 2. verschiedene Dokumente werden zur Verfügung gestellt: • Bericht der Bundesrepublik Deutschland für die sechste Überprüfungskonferenz im Mai 2018 Gemeinsames Übereinkommen über die Sicherheit der Behandlung abgebrannter Brennelemente und über die Sicherheit der Behandlung radioaktiver Abfälle • Richtlinie 2011/70/EURATOM des Rates vom 19. Juli 2011 über einen Gemeinschaftsrahmen für die verantwortungsvolle und sichere Entsorgung abgebrannter Brennelemente und radioaktiver Abfälle (ABl. Nr. L199 vom 2. August 2001, S. 48) • Dennis Köhnke, Manuel Reichardt, Franziska Semper Hrsg. Zwischenlagerung hochradioaktiver Abfälle, Springer Verlag, 2017 • GRS - A – 3597 Sicherheitstechnische Aspekte der langfristigen Zwischenlagerung von bestrahlten Brennelementen und verglastem HAW, April 2010 • EMPFEHLUNG der Entsorgungskommission (ESK)

	Leitlinien für die trockene Zwischenlagerung bestrahlter Brennelemente und Wärme entwickelnder radioaktiver Abfälle in Behältern • EMPFEHLUNG der Entsorgungskommission ESK-Leitlinien für die Zwischenlagerung von radioaktiven Abfällen mit vernachlässigbarer Wärmeentwicklung • DISKUSSIONSPAPIER der Entsorgungskommissiom Diskussionspapier zur verlängerten Zwischenlagerung bestrahlter Brennelemente und sonstiger Wärme entwickelnder radioaktiver Abfälle • STELLUNGNAHME der Entsorgungskommission Sicherheitskonzeptionelle Anforderungen an das Barrierensystem eines Endlagers für hoch radioaktive Abfälle und deren Umsetzbarkeit • EMPFEHLUNG der Entsorgungskommission Anforderungen an Endlagergebinde zur Endlagerung Wärme entwickelnder radioaktiver Abfälle • Anforderungen an endzulagernde radioaktive Abfälle (Endlagerungsbedingungen, Stand: Oktober 2010)- Endlager Konrad

Fuel and Waste Technology

Kennnummer	**Workload**	**Credits**	**Studiensemester**	**Häufigkeit des Angebots**	**Dauer**
	150 h	5	2./3. Sem.	once a year	1 Semester

	Lehrveranstaltungen	**Kontaktzeit**	**Selbststudium**	**geplante Gruppengröße**
1	1. Nuclear Fuels (335080) a) Lecture (2 SWS) 2. Nuclear Waste Technology a) Lecture (2 SWS) b) Seminar (1 SWS)	5 SWS / 75 h	75 h	20

2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. The students know the chemical and physical processes of the nuclear fuel cycle. They can explain how to extract uranium as starting material for fuel fabrication from uranium deposits. In particular, they will gain insights into the chemical processes involved in purifying the raw material. Besides chemistry, the students also can describe the physical methods of enrichment. They can categorize different nuclear fuels. Besides historical fuels, the fabrication of new fuels and the corresponding reactor concepts are presented. The students can explain the procedures to reprocess and dispose of nuclear fuels including new processes for the treatment of spent fuels. The students also get an insight into the current research topics on nuclear waste management. 2. Graduates know the key technologies in processing of waste and their possible application fields including best practice and methodologies. They understand that reflections or decisions on the application of technologies cannot be independently from official regulatory requirements as well as from site conditions, logistics or economic framework. They have developed a fundamental understanding about the efforts and their proportion to the objectives, taking into consideration the generation of secondary waste streams, too.

3	**Inhalte** 1. This lecture deals with the Nuclear fuel cycle with the following subtopics: Background to the Nuclear Fuel Cycle, Front-end of the fuel cycle: Geochemistry of uranium, Uranium Abundance, Occurrence and Commercial Deposits, Methods of Uranium Ore Mining, Uranium exploration, The Mining and Milling Process, Risks of uranium mining, Uranium Conversion Processes, Enrichment of U-235, Uranium Enrichment Methods, Manufacturing of nuclear fuel (metals, Oxides, From UF6 to fuel), Fuel fabrication – UO_2 powder to pellets, Advanced nuclear fuel materials (Mixed oxides, Th-based fuel,...). Fast rector fuel variants and reactor concepts, High-Temperature Reactor Fuel. Back-end of the fuel cycle: Reprocessing of spent fuel, PUREX Process, RadWaste Classification, Hydrochemistry – History, Solvent extraction, Off gas treatment and vitrification of high level radioactive waste, Actual Research for the safe management of nuclear waste. Alternative waste management concepts: Advanced Fuel cycle including Partitioning (actinide separation) and Transmutation (new reactor concepts for actinide burning). 2. This lecture deals with the pre-treatment, treatment and conditioning of radioactive waste, informing both about technologies (part I) and the interconnectedness of technical steps as well as overall requirements and framework conditions to management the waste processing (part II). The complete disposal management of a radioactive waste stream and and residuals using a main nuclear waste technology is demonstrated by the examples. In part II of this lecture an important waste stream is tracked along the whole predisposal chain, from operation to dismantling and nuclear waste management ending with either recycling/reuse, clearance or interim storage. • Part I – Technologies Pre-treatment, treatment and conditioning are the key elements of a comprehensive waste management system. Pre-treatment and treatment primarily aim at decontamination and/or volume reduction of the waste originally arising, whereas conditioning concerns the proper packing and/or stabilisation of the processed waste or waste products for long-term interim storage (according to final repository requirements, if existing). In this part the following topics are adressed: Technical: Processing of solid radioactive waste, Processing of liquid radioactive waste, Thermal treatment methods for radioactive waste, Waste immobilization and conditioning for storage and disposal Waste product qualities: Physics and Chemistry of cementation processes, Long term performance of nuclear waste forms • Part II – Significant relationships and dependencies in nuclear waste processing Decommissioning of nuclear facilities produces large quantities of slightly radioactive material which can be disposed of or reused, but first has to be cleared by the nuclear regulatory authority. The procedure to release such materials from nuclear regulatory control involves a series of measurements and conforming to national regulations and international standards. In this part a prominent waste stream is tracked throughout the whole predisposal chain. Besides technological aspects and their physical and chemical bases, the integration of a waste campaign into organisational and administrative procedures is demonstrated, including application, permits and monitoring. This also applies for secondary waste streams as well as breakdown into clearance and disposal paths.
4	**Lehrformen** 1. Lecture and Self-Study *2.* Lecture, Seminar and Self-Study
5	**Teilnahmevoraussetzungen**

	formal conditions: none information on preparation: For Nuclear Waste Technologies it is recommended to have attended the lecture "Nuclear Waste Management" before.
6	**Prüfungsformen** 1. Written exam (90 min) 2. Written exam (60 min, 70% of the grade) and group presentation with slides (30 min, 30% of the grade) (alternatively: individual presentation, 10 min) For the presentation: slides and individual performance are graded, as well as participation to the discussion afterwards.
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passing the module exams
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Langer **Lehrende:** 1. Prof. Dr. G. Modolo 2. Prof. Dr. Steinmetz, Dipl.-Ing. Kreh, Prof. Dr. Ojovan
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. P.D. Wilson, The nuclear fuel cycle, From the ore to waste, Oxford-New York-Tokyo, Oxford university press 1996 Nuclear Technology,Vol. 23 in Ullmanns Encyclopedia of industrial chemistry, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, 2005 Lieser, Nuclear and Radiochemistry, Fundamentals and Applications, VCH Verlagsgesellschaft 1991 Special literature (journals, book articles) will be referred during lecture Nuclear Fuel https://www.world-nuclear-news.org/ https://www.world-nuclear.org/… 2. Handout, Review articles Lecture notes and script International Atomic Energy Agency. Handling and Processing of Radioactive Waste from Nuclear Applications, Technical Report Series No. 402, IAEA, Vienna (2001), ISBN 92–0–100801–5 John R. Lamarsh & Anthony J. Baratta, "Introduction to Nuclear Engineering" PEARSON comp.; 4th edition, 2017, ISBN-10: 0134570057 M.I. Ojovan, W.E. Lee, S.N. Kalmykov. An introduction to nuclear waste immobilisation. Third edition, Elsevier, Amsterdam, 497 pp. (2019), ISBN: 978-0-08-102702-8 W.E. Lee, M.I. Ojovan, C.M. Jantzen. Radioactive waste management and contaminated site clean-up: Processes, technologies and international experience. Woodhead Publishing Series in Energy No. 48. ISBN 0 85709 435 1, Woodhead, Cambridge (2013).

Fundamentals in Nuclear Waste Management

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
335480	150 h	5	2./3. Sem.	once a year	1 Semester

1	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
	1. Nuclear Waste Management (335120) a) Lecture (2 SWS) b) Seminar (1 SWS) 2. Waste Management Concepts(335481) a) Seminar (2 SWS)	5 SWS / 75 h	75 h	20

2 Lernergebnisse (learning outcomes) / Kompetenzen

1. Students have all relevant knowledge of international and national legal standards with regard to predisposal and disposal of radioactive waste, in particular competences in the field of approval procedures. The students acquire in-depth knowledge in the classification and radiological evaluation of the various waste streams as well as in the relevant disposal paths and technologies. They know about relations and interdependencies in the thematic area of Nuclear Waste Management and are capable to apply this knowledge. In particular, they are able to understand and to consider waste management concepts.
2. Students are able to plan, efficiently contribute to or evaluate waste disposal concepts taking into consideration individual framework conditions, either technical, legal, financial or ecological including suitable alternatives or options, according to the international state-of-the-art. They are capable to understand main interdependencies and interconnections within or between the topic fields as well as responsibilities and targets of the various parties involved.
   Furthermore, the students acquire interdisciplinary qualifications that prepare them for the targeted presentation of matters, planning, status or results to decision makers, regulatory bodies, experts of various faculties and clients as well as the comprehensible presentation of complex issues to the specialist or general public. They have trained to concisely summarize complex facts and professional interrelations.
   Students are also informed and trained concerning special management qualities and communicative skills. They have gained basic knowledge of human information processing and proper operational decision making in order to assess and avoid risks and to minimize efforts in nuclear waste management tasks and projects. Moreover, they acquire the skills and interdisciplinary qualifications which prepare them to communicate with all parties involved in nuclear waste disposal projects or campaigns.

3 Inhalte

1. This course imparts basics and fundamental knowledge about the topic field of nuclear waste management. Specialists information, application-oriented knowledge and competences (subjects and methods) are provided or trained in the separate course “Waste Disposal Concepts”.
   Disposal is the final step of the life cycle of nuclear waste including used nuclear fuel declared as waste. Before final disposal, the nuclear waste usually goes through a number of steps such as pre-treatment, treatment, conditioning, storage and transport with characterization utilized within the entire cycle of radioactive waste.

	The safe management and storage of nuclear waste and used nuclear fuel depends largely upon the utilization of nuclear waste predisposal technologies. Predisposal management encompasses all steps that collectively cover the activities from waste generation up to final disposal, ending with interim storage, clearance or recycling. In this lecture all important steps within the generic disposal chain for radioactive waste are addressed and described, including the final or interim endpoints. The students get to know the most important organizational, technical and legal constraints and dependencies which have to be considered in predisposal management. The students will know about the radioactive waste classification systems worldwide, as well as the most important waste streams, including steps and options in their individual life cycle (operational waste from nuclear power generation, decommissioning waste, institutional waste as well as legacy waste). 2. This course complements and deepens the fundamental knowledge obtained in the lecture Nuclear Waste management. Moreover, professional capabilities and skills are trained and practiced in both an exercise and seminar part. All parts are affiliated with each other. Radwaste disposal concepts are usually subdivided according to three main topic fields: • Description of the radioactive waste or waste streams, particularly with regard to origin or generation, material composition and physico-chemical characterisation, radioactive inventory and harzardous properties, if any. • Nuclear Waste Management, considering legal framework and other boundary conditions or limiting factors. • Material and substance flows In order to understand the complex assignments and efforts and connected with radwaste disposal concepts both main aspects and selected important topics are addressed. Part I – Waste streams The lecture provides a comprehensive introduction into the subject field of radioactive waste streams worldwide, in particular „Problematic Radioactive Wastes" (including legacy waste) and „Challenging Waste Streams". Challenges may range from (1) the absence of a suitable processing technology through (2) to waste stream whose characteristics was not taken into account in the definition of the waste acceptance criteria for the available disposal solutions, or which (3) do not longer meet specifications for safe storage or final disposal. The latter may be due to physically or chemically induced changes of the waste composition or properties, e.g. ageing, corrosion of the waste packages, new scientific findings or revisions of waste acceptance criteria. To facilitate the disposition of these challenging waste streams, an integrated radioactive waste management approach is required involving all close cooperation between the regulators, waste processors and disposal facility operators. This important integrated view is conveyed in a sustainable way. Part II - Teamwork and discussion on waste disposal concepts Aiming at integrated disposal concepts the students are made familiar with various tasks, approaches and strategies to deal with radioactive waste in a wide range of application areas for radionuclides or activities/processes in medicine, research, and technology. This also includes secondary radioactive wastes streams, by-products or residues from industrial production or mining (e.g. NORM - Naturally Occurring Radioactive Material). Basic information, literature and references are provided by the supervisor/lecturer in handouts. In groups of typically 3 students compile and structure information about complex matters, extract relevant content and report results and conclusions to the auditorium in a well understandable form reduced on the main issues and key points. Fostered and guided by the supervisor participants do discuss on the descriptions and perceptions of the individual groups. In order to stimulate conceptional and interdisciplinary thinking or critical reflections the students are provided both holistic views and additional details or background information by the supervisor/lecturer. Part III - Qualities and skills in nuclear waste disposal and management

	Safe and successful nuclear waste management is not only based on profound technical expertise and integrated overview. It also requires special management qualities and communicative skills in combination with circumspection, foresight and sensitivity as well as the ability to deal with uncertainty factors. Introducing into the subject, some fatal nuclear and non-nuclear accidents are described and comparatively analysed regarding the human factor. Examples are the reactor accident of Chernobyl NPP in 1986, the NASA Challenger catastrophe in 1986 and the German high-speed train accident at Eschede in 1998. Main topics are perception, attention, learning, memory, thinking and problem solving. Subsequently, these topics will be discussed on the basis of typical applications, and methods to optimize/reduce errors are developed. They are partly demonstrated via role-plays and using test exercises. In addition, essential basics of communication and decision-making are addressed. Guided by the lecturer they are tested in group-works based on the theoretical principles.
4	**Lehrformen** Lecture, Seminar, Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Written exam (90 min) 2. oral exam (30 min), participation to discussions and questions asked during the block course gives bonus point (up to 30/100)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Mandatory attendance Passed module exams, passed report
8	**Verwendung des Moduls** (in anderen Studiengängen) **None**
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Steinmetz **Lehrende:** 1. Prof. Dr. Steinmetz, Prof. Dr. Ojovan (Imperial College London, UK) 2. Prof. Dr. Steinmetz, Prof. Dr. Ojovan (Imperial College London), Prof. Dr. Echterhoff (Universität Wuppertal), Dr. Anke Trautmann
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. Handout, Review articles Lecture notes and script John R. Lamarsh & Anthony J. Baratta, "Introduction to Nuclear Engineering" PEARSON comp.; 4th edition, 2017, ISBN-10: 0134570057

	M. Stacey, Nuclear Reactor Physics, Wiley Interscience 2001, ISBN 0471391271 2. Handouts, Review articles Lecture notes and script John R. Lamarsh & Anthony J. Baratta, "Introduction to Nuclear Engineering", PEARSON comp.; 4th edition, 2017, ISBN-10: 0134570057 M. Stacey, Nuclear Reactor Physics, Wiley Interscience 2001, ISBN 0471391271 W. Dörner, "The Logic of Failure: Recognizing and Avoiding Error in Complex Situations", Basic Books; Revised ed., ISBN 978-0201479485 (1997)

Materials in Nuclear Waste Management

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
	150 h	5	2./3. Sem.	once a year	1 Semester

1	**Lehrveranstaltungen** 1. Ageing Phenomena in Nuclear Materials a) Lecture (2 SWS) 2. Ageing Management a) Lecture (2 SWS)	**Kontaktzeit** 4 SWS / 60 h	**Selbststudium** 90 h	**geplante Gruppengröße** 20
2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. The students are able to describe physical-chemical degradation processes for materials such as metals, technical plastics and mineral materials, which are used for buildings, packages and their inventories. They get familiar with relevant destructive and non-destructive methods for damage diagnosis and gain an understanding of spent fuel behavior under dry storage conditions. 2. The student is familiar with the methods of ageing management. They are able to evaluate ageing phenomena and control their effects by appropriate countermeasures.			
3	**Inhalte** 1. Structure and properties of materials relevant for nuclear waste management as metal, technical plastics and mineral materials, thermal and radiological ageing effects, point defects (vacancies, atoms on interstitial sites), texture, dislocation, radiolysis, ageing mechanism for selected examples as embrittlement, creeping, corrosion, excessive wear, whisker formation, electromigration, oxidation/passivation, material fatigue, plastic elongation/deformation, carbonization of concrete, non-destructive testing methods, property changes of spent fuel assemblies/ fuel rods/ cladding during lifetime 2. Kinds of ageing, scope of ageing management, scope of periodic safety review, PDCA-cycle as a concept for ageing management, IAEA-philosophy, classification of structures, systems, components on the basis of their function and their safety-relevance, monitoring concept to monitor the implementation of control and surveillance measures, recurring inspections, ageing relevant characteristics and test criterions for selected examples, preventive and failure-oriented maintenance, documentation			
4	**Lehrformen** 1. Lecture, Self-study 2. Lecture, team work and guided discussion, self-study			
5	**Teilnahmevoraussetzungen**			

	formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Written exam (90 min) or oral exam (30 min) depending on number of students 2. Oral exam (30 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed module exams and contribution to group oral report for the course "Ageing Management"
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Steinmetz **Lehrende:** 1. Dr. Maik Stuke (BGZ), Marc Péridis (BGZ) 2. Priv.-Doz. Dr. Astrid Jussofie (BGZ), Dr. Robert Brüninghoff (BGZ), Dr. Maik Stuke (BGZ)
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. IAEA Technical Reports Series No. 443 Understanding and Managing Ageing of Material in Spent Fuel Storage Facilities 2. Handout IAEA Specific Safety Guide No. SSG-48 Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants IAEA NUCLEAR ENERGY SERIES No. NP-T-3.24 Handbook on Ageing Management on for Nuclear Power Plants IAEA Safety Report Series No. 62 Proactive Management of Ageing for Nuclear Power Plants Report by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) on Topical Peer Review Ageing Management of Nuclear Power Plants and Research Reactors ESK guidelines for the performance of periodic safety reviews and on technical ageing management for storage facilities for spent fuel and heat-generating radioactive waste

Nuclear Fuels and Actinide Chemistry

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer

335340	150 h	5	2./3. Sem.	once a year	1 Semester

1	**Lehrveranstaltungen** 1. Nuclear Fuels (335080) a) Lecture (2 SWS) 2. Actinide Chemistry (335010) a) Lecture (2 SWS)	**Kontaktzeit** 4 SWS / 60 h	**Selbststudium** 90 h	**geplante Gruppengröße** 20

2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. The students know the chemical and physical processes of the nuclear fuel cycle. They can explain how to extract uranium as starting material for fuel fabrication from uranium deposits. In particular, they will gain insights into the chemical processes involved in purifying the raw material. Besides chemistry, the students also can describe the physical methods of enrichment. They can categorize different nuclear fuels. Besides historical fuels, the fabrication of new fuels and the corresponding reactor concepts are presented. The students can explain the procedures to reprocess and dispose of nuclear fuels including new processes for the treatment of spent fuels. The students also get an insight into the current research topics on nuclear waste management. 2. Students acquire knowledge on the chemical properties and chemistry of actinide elements. They can describe their relevance for applications and in the environment. They know basic methods of their analysis and measurement of their radiations and can apply them to practical cases.
3	**Inhalte** 1. This lecture deals with the Nuclear fuel cycle with the following subtopics: Background to the Nuclear Fuel Cycle, Front-end of the fuel cycle: Geochemistry of uranium, Uranium Abundance, Occurrence and Commercial Deposits, Methods of Uranium Ore Mining, Uranium exploration, The Mining and Milling Process, Risks of uranium mining, Uranium Conversion Processes, Enrichment of U-235, Uranium Enrichment Methods, Manufacturing of nuclear fuel (metals, Oxides, From UF6 to fuel), Fuel fabrication – UO_2 powder to pellets, Advanced nuclear fuel materials (Mixed oxides, Th-based fuel,...). Fast rector fuel variants and reactor concepts, High-Temperature Reactor Fuel. Back-end of the fuel cycle: Reprocessing of spent fuel, PUREX Process, RadWaste Classification, Hydrochemistry – History, Solvent extraction, Off gas treatment and vitrification of high level radioactive waste, Actual Research for the safe management of nuclear waste. Alternative waste management concepts: Advanced Fuel cycle including Partitioning (actinide separation) and Transmutation (new reactor concepts for actinide burning). 2. Synthesis of Actinides; Nuclear Structure and Decay properties; Chemical Properties: Periodic table, gas phase electronic structure, ionic radii, oxidation states, speciation (hydrolysis, complex formation, redox), chemical separation methods, metallic state, inorganic compounds, organometallic compounds, Presence in nature: compounds, nucleosynthesis, origin; Applications: Nuclear power, nuclear weapons, power sources, industrial applications, medical applications
4	**Lehrformen** Lecture, Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: It is recommended that the students have already attended the lecture Nuclear Chemistry before attending the course Actinide Chemistry.

6	**Prüfungsformen** 1. Written exam (90 min) 2. Written exam (90 min) or oral exam (20 min) depending on number of students, Presentation (10 min, required for admittance to exam)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passing the module exams
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Paulßen **Lehrende:** 1. Prof. Dr. Modolo 2. Dr. Daniels
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. P.D. Wilson, The nuclear fuel cycle, From the ore to waste, Oxford-New York-Tokyo, Oxford university press 1996 Nuclear Technology,Vol. 23 in Ullmanns Encyclopedia of industrial chemistry, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, 2005 Lieser, Nuclear and Radiochemistry, Fundamentals and Applications, VCH Verlagsgesellschaft 1991 Special literature (journals, book articles) will be referred during lecture Nuclear Fuel https://www.world-nuclear-news.org/ https://www.world-nuclear.org/… 2. G.Choppin, J.-O. Liljenzin, J. Rydberg, Radiochemistry and Nuclear Chemistry, Butterworth Heinemann, 3rd ed., 2000, ISBN 0-7506-7463-6; Nuclear Chemistry, Lieser, Chieme Verlag, 2001; The Chemistry of the Actinide and Transactinide Elements, Mors, Edelstein, Fuger & Katz (Eds.), Springer Science + Business Media B.V., 2008

Nuclear Medicine and Imaging

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
	150	5	2./3. Sem.	once a year	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	1. Nuclear Medicine (335100)	4 SWS / 60 h	90 h	

	a) Lecture (2 SWS) 2. Nuclear Imaging (335090) a) Lecture (2 SWS)			20

2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. The students become familiar with the procedures applied in nuclear medicine. They know how to perform quality controls for the variety of devices used and to perform imaging using different modalities. They can do simple dose calculations for typical therapy modes. 2. Students develop an insight into the application of radiation measurement to imaging technologies. They identify different detection principles and the methods to create 2D/3D images and can explain various reconstruction techniques. They can show how these elements are used in concurrent medical imaging devices.
3	**Inhalte** 1. Clinical procedures: a typical patient case. Imaging modalities and their applications for the diagnosis of diseases of different organs and tumors. Dosimetric measurements, checks and quality controls. Disease treatment with open radionuclides and patient individual dosimetry. 2. The content of the course includes: • an introduction to CT and advanced MRI imaging methods • recent advances into single-photon emission computed tomography (SPECT) and • positron emission tomography (PET) imaging • hybrid imaging techniques that combine exceptional functional and physiologic imaging capabilities of SPECT and PET with the anatomically detailed techniques of CT and MRI • tomographic image reconstruction methods based on filtered back-projection principle and iterative maximum likelihood estimation and maximization procedures • correction methods for quantification
4	**Lehrformen** Lecture, Self-study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 1. Written exam (90 min) 2. Written exam (90 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passing the module exams
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %

10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Ziemons **Lehrende:** 1. Priv.-Doz. Dr. med. Hautzel 2. Prof. Dr. Ziemons, Dr. Lohmann
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. Lecture slides will be made available to the students 2. William R. Hendee, E.R.Ritenour, Medical Imaging Physics, Wiley, 2002, ISBN 0471382264 Simon R.Cherry, James A. Sorensen, Michael E.Phelps, Physics in Nuclear Medicine, Elsevier, 2012, ISBN 978-1-4160-5198-5 Gengsheng Lawrence Zeng, Image Reconstruction: Applications in Medical Sciences, De Gruyter, 2017, ISBN 978-3110500486

Nuclear Power Generation & Nuclear Materials

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
335110	150 h	5	2./3. Sem.	once a year	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	Nuclear Power Generation & Nuclear Materials a) Lecture (4 SWS)	4 SWS / 60 h	90 h	10

2	**Lernergebnisse (learning outcomes) / Kompetenzen** Students get a detailed insight in the setup and operation of a pressurized water reactor and its auxiliary and ancillary systems. Included are different modern forms of this type as the Konvoi, the N4, the EPR and the VVER units. A short introduction to the technology of boiling water reactors is given as well. As power generation is discussed, the generator and the power supply system (emergency and normal) are included. For both types of nuclear power stations, the applied materials are discussed. In the simulator part, the students learn to analyse the indicated parameters and draw conclusions on the actual state of the NPP. In different experiments, reactivity-related parameters are measured. In addition, the start-up of the reactor from undercritical hot to full load is simulated.
3	**Inhalte** NPP with PWR: primary circuit, core components, core instrumentation, introduction to the thermohydraulic design, secondary circuit, nuclear operation practice, control, limitation and protection functions of the nuclear power plant, electric plant NPP with BWR: overview of the plant, reactor control, accident scenario Fukushima

4	**Lehrformen** Lecture, Simulator Lab (The two last lecture days are spent for simulation of a VVER-1000.), Self-study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** 30 min oral examination or (for larger groups) 120 min written examination
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passing the module exam
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** Prof. Dr. Neubauer
11	**Sonstige Informationen**

Nuclear Technology Lab

Kennnummer	**Workload**	**Credits**	**Studiensemester**	**Häufigkeit des Angebots**	**Dauer**
335370	150 h	5	2./3. Sem.	once a year	1 Semester

	Lehrveranstaltungen	**Kontaktzeit**	**Selbststudium**	**geplante Gruppengröße**
1	1. Environmental Radiation Detection (335060) a) Practical Training (2 SWS) 2. Reactor Lab (335170) a) Practical Training (2 SWS)	4 SWS / 60 h	90 h	1. 6 2. 12

2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. The students recognise the required methods of radiation detection for environmental radionuclides. They select appropriate methods for the practical solution of the task including appropriate sample treatment and chemical separation and perform measurements. They use alternative methods of measurement and calculation of the data in-

	cluding the analysis of the measurement uncertainties. They report their results in common standard formats and discuss the relevance of the results. The students understand the analytical use of X-rays and can explain the different methods. They are able to perform different types of X-ray Fluorescence Analysis. 2. The students gain understanding of the principles of reactor physics and reactor operation by performing typical experiments of neutron physics and reactor static and dynamic behavior.
3	**Inhalte** 1. Samples will be collected from the environment, chemically treated and measured to determine their radionuclide content. 2. The reactor lab constains: a. Introduction to a typical research reactor, e.g. VR-1. b. Measurement of delayed neutrons and studying reactor dynamics. c. Reactivity: influence of bubbly boiling. d. Measurements and characterization of the neutron flux (foils, activations wire, ionization chambers). e. Controls: design and operation of control equipment, demonstration of control equipment functions and training of reactor control and safety experiments
4	**Lehrformen** Practical Training, Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: none
6	**Prüfungsformen** Reports (10 - 20 pages) and Presentations (20 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed reports
8	**Verwendung des Moduls** (in anderen Studiengängen) **None**
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Langer **Lehrende:** 1. Prof. Dr. Paulßen 2. Prof. Dr. Langer, Prof. Dr. Neubauer
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. Course Information will be given on Ilias 2. Laboratory Manual of Reactor Experiments with VR-1

Strahlenschutzkurs für Medizinphysiker[4]

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
335390	150 h	5	2./3. Sem.	once a year	Blockveranstaltung

1	**Lehrveranstaltungen** Strahlenschutzkurs für Medizinphysiker a) Vorlesung (3 SWS) b) Praktikum (1 SWS)	**Kontaktzeit** 72 h	**Selbststudium** 78 h	**geplante Gruppengröße** max. 6 Teilnehmer
2	**Lernergebnisse (learning outcomes) / Kompetenzen** Die Studierenden haben die zum Erwerb der Fachkunde als Medizinphysiker nach dem geltenden Richtlinienmodul „Erforderliche Fachkunden im Strahlenschutz für Medizinphysik-Experten (MPE)“ (zum neuen Strahlenschutzrecht auf den Gebieten Teletherapie und Röntgendiagnostik) notwendigen behördlich genehmigten Kurse erfolgreich absolviert (es wird ein entsprechendes Zertifikat erteilt). Der Fachkundeerwerb muss dann spätestens nach 5 Jahren erfolgt sein, ansonsten sind die Kurse zu wiederholen. Da die Schulung auf der Basis des deutschen Strahlenschutzrechtes erfolgt und einer behördlichen Genehmigungspflicht unterliegt ist die Unterrichtssprache Deutsch. Der enthaltene Grundkurs kann auch als Basis für den Erwerb der Fachkunde für MPE in der Nuklearmedizin und Brachytherapie genutzt werden.			
3	**Inhalte** Gemäß den Vorgaben der Richtlinie sind Kursinhalte: Grundlagen der Strahlenphysik und -biologie (deterministische und stochastische Strahlenwirkung einschl. Wirkung auf Tumorgewebe); Dosisbegriffe und Dosimetrie; Grundlagen und Grundprinzipien des Strahlenschutzes; natürliche und zivilisatorische Exposition des Menschen; Strahlenschutzrecht einschl. Richtlinien, Empfehlungen, Regeln der Technik, Regelungen zu Notfallsituationen und Vorkommnissen bei Anwendung ionisierender Strahlung am Menschen; Röntgendiagnostik (im Rahmen des Grundkurses sowie für Hybridverfahren); radioaktive Stoffe in der Medizin (radioaktive Arzneimittel) – nur noch in begrenztem Umfang, Aufbau und Funktion med. Bestrahlungseinrichtungen; Qualitätssicherung für alle Gebiete, Bestrahlungsgeräte und Anwendungsverfahren; Arbeitsanweisungen; Bestrahlungsplanung in der Teletherapie; Strahlenschutz von Patient, Personal und Umwelt für alle Anwendungsgebiete inkl. baulichen und apparativen Strahlenschutz; Strahlenschutzüberwachung und –aufzeichnung, rechtfertigende Indikation und diagnostische Referenzwerte			
4	**Lehrformen** Vorlesung und Praktikum (incl. einer ganztägigen Veranstaltung in der Klinik für Strahlentherapie und Radioonkologie der HHU Düsseldorf) sowie Selbststudium			
5	**Teilnahmevoraussetzungen** formale Voraussetzungen: keine			

[4] This module will be only offered in German.

	Informationen zur Vorbereitung: Grundlagen auf dem Gebiet der Atom- und Kernphysik (ggf. auch biol. Strahlenwirkungen und/ oder med. Bildgebung) sollten vorhanden sein.
6	**Prüfungsformen** Schriftliche Abschlussprüfungen (30 - 120 min) nach den einzelnen Kursmodulen (Grund- und Basiskurse). Voraussetzung für das Bestehen der Prüfungen gemäß Richtlinie bzw. Genehmigungsauflage: es müssen mehr als 70% der erreichbaren Punktzahl erlangt werden.
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Bestehen der beiden schriftlichen Prüfungen und lückenlose Teilnahme an den Praktika.
8	**Verwendung des Moduls** (in anderen Studiengängen) Einstieg in den zwei Jahre umfassenden Sachkundeerwerb für angehende Medizinphysik-Experten und notwendige Grundlage für den Fachkundeerwerb.
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Langer **Lehrende:** Dr. Marten-Tölle als Leiterin der Kursstätte und Kursleitung - es unterrichtet eine größere Anzahl Dozenten der Kursstätte für Strahlenschutz
11	**Sonstige Informationen** **Literatur und Lernunterlagen** Die Kursteilnehmer erhalten ein Skript.

Radionuclide Production and Radiopharmacy

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
335400	150 h	5	2./3. Sem.	once a year	2 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	1. Radionuclide Production (335160) a) Lecture (2 SWS) 2. Labeling and Radiopharmaceutical Chemistry (335070) a) Lecture (2 SWS)	4 SWS / 60 h	90 h	20
2	**Lernergebnisse (learning outcomes) / Kompetenzen**			

	1. Students learn production technologies at nuclear reactors and cyclotrons of all commonly used radionuclides. They understand practical processes for radionuclide production and separation using wet and dry methods. They can plan the design of production targets and can generate a system of quality control procedures for the radionuclide. In addition, they can develop schemes for production of novel radionuclides based on the requirements of their use. 2. The students develop a detailed insight into radiolabeling strategies for a number of relevant radionuclides. They apply chemical knowledge to solve the problems integrating to requirements of the radiotracers to be produced into the synthesis processes. Students derive the conditions for the safe production of radiopharmaceuticals. They can select proper strategies for the development of novel radiopharmaceutical and can propose their proper usage.
3	**Inhalte** 1. General introduction to radionuclides suitable for applications; Production technology: use of nuclear data, irradiation techniques, target development, heat generation, in-situ chemical reactions, chemical processing via dry and wet methods, yield determination. Quality control of the product (radionuclidic, radiochemical, chemical). Production procedures of some commonly used radionuclides. Development of novel radionuclides for applications (requirements, challenges, perspectives). 2. Radionuclide Generators; Methods of Radiolabeling: Radioiodination, Radiofluorination, Labeling with Tc-99m and other Radiometals, Labeling with tritium, carbon-14 and carbon-11; Labeling Efficiency, Chemical Stability, Isotope Effect; Carrier-Free or No-Carrier-Added (NCA) State; Purification and Analysis; Definition of a Radiopharmaceutical; Quality Control of Radiopharmaceuticals: Physicochemical Tests, Biological Tests, Record Keeping; Nuclear Pharmacy; Design of New Radiopharmaceuticals; Uses of Radiopharmaceuticals.
4	**Lehrformen** Lecture, Self-Study
5	**Teilnahmevoraussetzungen** formal conditions: none information on preparation: 1. Basic knowledge of chemistry/physics/engineering 2. Knowledge of inorganic and organic chemistry
6	**Prüfungsformen** 1. 90 min written examination 2. 120 min written examination
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passing the exam for each lecture.
8	**Verwendung des Moduls** (in anderen Studiengängen) none
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende**

	Modulbeauftragte: Prof. Dr. Paulßen **Lehrende:** 1. Prof. Dr. Dr. h. c. mult. Qaim 2. Prof. Dr. J. Ermert
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. Radionuclide Production: • Handout; • Review articles; • S.M.Qaim: Medical Radionuclide Production (Science and Technology), De Gruyter, Berlin, 2019, ISBN 978-3-11-060156-5 2. Labeling and Radiopharmaceutical Chemistry: • Handout • Review articles • Jason S. Lewis, Albert D. Windhorst, Brian M. Zeglis, Eds., Radiopharmaceutical Chemistry, 2019, ISBN 9783319989471 • Saha, Fundamentals of Nuclear Pharmacy, Springer, 2010, ISBN 9781489982124

Waste Products and Waste Packages

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
335520	150 h	5	2./3. Sem.	once a year	1 Semester

	Lehrveranstaltungen	Kontaktzeit	Selbststudium	geplante Gruppengröße
1	1. Decommissioning (335040) a) Lecture (2 SWS) 2. Nuclear Waste Technology a) Lecture (2 SWS) b) Seminar (1 SWS)	5 SWS / 75 h	75 h	20

2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. The students assess methods to dismantle and decontaminate plants. They realize the steps to a "Green field site" and the meaning of the different periods. They illustrate essential separation and disassembly techniques as well as decontamination technologies suitable for decommissioning. They exemplify by previous and recent decommissioning projects at the site. They are able to integrate the various procedures and propose generalized approaches. The students learn about the main problems and solutions with regard to radiation protection during decommissioning. They know the essential methods which can be used for the clearance measurement of buildings. They can distinguish the different ways of a dismantled component which lead to disposal or clearance measurement. 2. Graduates know the key technologies in processing of waste and their possible application fields including best practice and methodologies.

	They understand that reflections or decisions on the application of technologies cannot be independently from official regulatory requirements as well as from site conditions, logistics or economic framework. They have developed a fundamental understanding about the efforts and their proportion to the objectives, taking into consideration the generation of secondary waste streams, too.
3	**Inhalte** 1. Inventories: measurement methods, dismantling; decontamination; legal requirements • From the final shut down until the first step of decommissioning • Separation and disassembly techniques and equipment for the dismantling of nuclear installations – including legal requirements • Decontamination technologies • Radiation protection during decommissioning • Clearance measurement of buildings • Waste management, disposal and clearance measurement of components 2. This lecture deals with the pre-treatment, treatment and conditioning of radioactive waste, informing both about technologies (part I) and the interconnectedness of technical steps as well as overall requirements and framework conditions to management the waste processing (part II). The complete disposal management of a radioactive waste stream and and residuals using a main nuclear waste technology is demonstrated by the examples. In part II of this lecture an important waste stream is tracked along the whole predisposal chain, from operation to dismantling and nuclear waste management ending with either recycling/reuse, clearance or interim storage. • Part I – Technologies Pre-treatment, treatment and conditioning are the key elements of a comprehensive waste management system. Pre-treatment and treatment primarily aim at decontamination and/or volume reduction of the waste originally arising, whereas conditioning concerns the proper packing and/or stabilisation of the processed waste or waste products for long-term interim storage (according to final repository requirements, if existing). In this part the following topics are adressed: Technical: Processing of solid radioactive waste, Processing of liquid radioactive waste, Thermal treatment methods for radioactive waste, Waste immobilization and conditioning for storage and disposal Waste product qualities: Physics and Chemistry of cementation processes, Long term performance of nuclear waste forms • Part II – Significant relationships and dependencies in nuclear waste processing Decommissioning of nuclear facilities produces large quantities of slightly radioactive material which can be disposed of or reused, but first has to be cleared by the nuclear regulatory authority. The procedure to release such materials from nuclear regulatory control involves a series of measurements and conforming to national regulations and international standards. In this part a prominent waste stream is tracked throughout the whole predisposal chain. Besides technological aspects and their physical and chemical bases, the integration of a waste campaign into organisational and administrative procedures is demonstrated, including application, permits and monitoring. This also applies for secondary waste streams as well as breakdown into clearance and disposal paths.
4	**Lehrformen** 1. Lecture, Self-study 2. Lecture, Seminar and Self-Study
5	**Teilnahmevoraussetzungen**

	formal conditions: none information on preparation: For Nuclear Waste Technologies it is recommended to have attended the lecture “Nuclear Waste Management” before.
6	**Prüfungsformen** 1. Written exam (90 min) 2. Written exam (60 min, 70% of the grade) and group presentation with slides (30 min, 30% of the grade) (alternatively: individual presentation, 10 min) For the presentation: slides and individual performance are graded, as well as participation to the discussion afterwards.
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passing the module exams
8	**Verwendung des Moduls** (in anderen Studiengängen) **None**
9	**Stellenwert der Note für die Endnote** 4,17 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** **Modulbeauftragter:** Prof. Dr. Steinmetz **Lehrende:** 1. Burkhard Stahn (Leiter Rückbauprojekte, JEN) 2. Prof. Dr. Steinmetz, Dipl.-Ing. Kreh, Priv.-Doz. Dr. Schlenz, Prof. Dr. Ojovan
11	**Sonstige Informationen** **Literatur und Lernunterlagen** 1. I Transition from Operation to Decommissiong of Nuclear Installations, IAEA, 2004; C.R. Bayliss, K.F. Langley: Nuclear Decommissioning, Waste Management, and Environmental Site Remediation, Butterworth-Heinemann, 2003 Chang Ho Oh (ed.) Hazardous and Radioactive Waste Treatment Technologies Handbook, CRC Press, 2001, ISBN 0849395860 2. Handout, Review articles Lecture notes and script International Atomic Energy Agency. Handling and Processing of Radioactive Waste from Nuclear Applications, Technical Report Series No. 402, IAEA, Vienna (2001), ISBN 92–0–100801–5 John R. Lamarsh & Anthony J. Baratta, “Introduction to Nuclear Engineering” PEARSON comp.; 4th edition, 2017, ISBN-10: 0134570057 M.I. Ojovan, W.E. Lee, S.N. Kalmykov. An introduction to nuclear waste immobilisation. Third edition, Elsevier, Amsterdam, 497 pp. (2019), ISBN: 978-0-08-102702-8 W.E. Lee, M.I. Ojovan, C.M. Jantzen. Radioactive waste management and contaminated site clean-up: Processes, technologies and international experience. Woodhead Publishing Series in Energy No. 48. ISBN 0 85709 435 1, Woodhead, Cambridge (2013).

Masterarbeit (Master Thesis)

In der Masterarbeit (27 ECTS) wenden die Studierenden die erworbenen Kompetenzen auf eine konkrete Fragestellung im Rahmen eines Forschungs- oder Entwicklungsprojektes an. Die Arbeiten können in den hauseigenen Laboratorien, Forschungs- oder Industrieeinrichtungen durchgeführt werden. Die Arbeit wird schriftlich als wissenschaftliche Arbeit dokumentiert. Die Masterarbeit wird mit einer Verteidigung (3 ECTS) abgeschlossen.

In their Master Thesis (27 ECTS) the students apply the acquired competences to solve a concrete problem within an R&D project. The thesis is performed in our own laboratories, public or industrial research institutions. The project is documented in a scientific paper. The thesis is concluded with a defense (3 ECTS).

Master Thesis

Kennnummer	Workload	Credits	Studiensemester	Häufigkeit des Angebots	Dauer
	900 h	30	4. Sem.	-	1 Semester

1	**Lehrveranstaltungen** 1. Thesis Paper (27 credits) 2. Defence of Thesis (3 credits)	**Kontaktzeit** -	**Selbststudium** -	**geplante Gruppengröße**
2	**Lernergebnisse (learning outcomes) / Kompetenzen** 1. In their Master Thesis (27 ECTS) the students apply the acquired competences to solve a concrete problem within an R&D project. The students find relevant literature in scientific and other databases. The thesis is performed in our own laboratories, public or industrial research institutions. The project is documented in a scientific paper. 2. The students present their research project (methods chosen, results and analysis) and are able to discuss all related questions in a public hearing.			
3	**Inhalte** 1. The students work independently on a self-chosen R&D project. They perform a literature research to define the state-of-the-art and propose solutions based thereupon. They structure their project and perform the work related to it. They discuss the results and hallmarks with the project team. They keep the records of their work, analyze, discuss and interpret the data. They document the work as a scientific paper. 2. Presentation and discussion of research results.			
4	**Lehrformen** self-study			
5	**Teilnahmevoraussetzungen** Formal conditions: 1. 80 Credits achieved within the Master Program 2. Submission of thesis			
6	**Prüfungsformen**			

	1. Scientific paper (thesis, 30 - 100 pages, or written in form of a scientific paper) 2. Presentation (20 min) and Oral examination (appr. 30 min)
7	**Voraussetzungen für die Vergabe von Kreditpunkten** Passed scientific paper and thesis defence
8	**Verwendung des Moduls** (in anderen Studiengängen) None
9	**Stellenwert der Note für die Endnote** 25 %
10	**Modulbeauftragte/r und hauptamtlich Lehrende** all professors of the FH Aachen within the study program
11	**Sonstige Informationen** **Literatur und Lernunterlagen**