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Relevance

This deliverable contributes to the following Work-Packages and Tasks:

☐ ALL

WP 1
☒ Task 1.1 ☐ Task 1.2 ☐ Task 1.3 ☐ Task 1.4

WP 2
☐ Task 2.1 ☐ Task 2.2 ☐ Task 2.3 ☐ Task 2.4

WP 3
☐ Task 3.1 ☐ Task 3.2 ☐ Task 3.3 ☐ Task 3.4 ☐ Task 3.5

WP 4
☐ Task 4.1 ☐ Task 4.2 ☐ Task 4.3 ☐ Task 4.4

WP 5
☐ Task 5.1 ☐ Task 5.2 ☐ Task 5.3 ☐ Task 5.4

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EXECUTIVE SUMMARY

Deliverable 1.1 covers the minimum requirements for NRC EuroMaster's degree (WP1, Task 1.1). Basis for these requirements was defined already during CINCH-I and they have been discussed in several project meetings as well as presented in public work-shops and nuclear and radiochemistry conference. The final version of the minimum requirements defines master's program eligible to NRC Euromaster label both as a structure and suggested content of the curricula. Most relevant topic areas are presented in details.

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1 INTRODUCTION

Development and implementation of the EuroMaster in Nuclear and Radiochemistry (NRC EuroMaster) is one of the main tasks in CINCH (Cooperation in education and training in nuclear chemistry - http://cinch-project.eu/) II project. The aim of the NRC EuroMaster is to give the European NRC students good common knowledge and skills in nuclear and radiochemistry and thereby harmonize, at a minimum level, the teaching programs in European universities. Structure and suggested content of the curricula for NRC EuroMaster are defined as **minimum requirements for NRC EuroMaster's degree**. Universities fulfilling the minimum requirements are allowed to grant the NRC EuroMaster label to their students. These universities will also form a network to promote NRC education in Europe and to organize student exchange and common courses. Basis for the minimum requirements were defined already during CINCH I and they have been discussed in several project meetings as well as presented in public work-shops and nuclear and radiochemistry conference. Final version of the document is described here.

2 MINIMUM REQUIREMENTS FOR THE EUROMASTER IN NUCLEAR AND RADIOCHEMISTRY (NRC EUROMASTER)

2.1 Granting system of NRC EuroMaster label

The NRC EuroMaster label is granted to the universities by the Nuclear and Radiochemistry Division of the European Association for Chemical and Molecular Sciences (EuCheMS NRC Division). The Division will evaluate the candidate universities by comparing their NRC curricula to the minimum requirements set in this document. If the NRC curriculum fulfills the requirements by 90% the university will be given the right to grant NRC EuroMaster to their NRC students and the university will become a member in the NRC EuroMaster Network.

2.2 Structure of EuroMaster in Nuclear and Radiochemistry (NRC)

The master’s program should contain at least 60 ECTS credit units (50% in case of 120 ECTS cu master's program) studies in nuclear and radiochemistry in the following way:

BSc in chemistry		180 cu
Compulsory studies in nuclear and radiochemistry (of which at least 10 cu exercises)	minimum	25 cu
Optional studies in nuclear and radiochemistry	minimum	10 cu
Project work and master’s thesis in nuclear and radiochemistry	minimum	30 cu
Elective studies		rest
In total		300 cu

For master’s programs having other volume than 120 ECTS credit units the workload of nuclear and radiochemistry studies should be equivalent to at least 60 ECTS credit units.

2.2.1 Aim

The aims of the NRC EuroMaster is to give the European NRC students good common knowledge and skills in nuclear and radiochemistry and thereby harmonize, at a minimum level, the teaching programs in European universities. A further aim of the NRC EuroMaster in to promote the exchange of students, teachers and teaching tools and help employment of nuclear and radiochemists at a European level.

2.2.2 Intended learning outcomes

On completion of the NRC EuroMaster program the student should have the following knowledge, abilities and skills:

1 Subject knowledge:

Recall the underlying principles of nuclear and radiochemistry
Explain the main practical aspects of nuclear and radiochemistry

2 Abilities and skills:

Perform essential radiochemistry related calculations
Work safely in a radiochemistry laboratory
Perform chemical reactions including radionuclides
Use a range of radiation measurement techniques
Handle radioactive materials safely
Identify the hazards pertaining to a radionuclide

2.2.3 Compulsory studies on nuclear and radiochemistry (25 cu)

In the following topic areas (1-6) and under them topics that need to be covered are listed. The topic areas do not refer to any specific courses which can be organised in various ways. Teaching can consist of lecture and laboratory exercise modules as well as of exams. If a part of the topics listed below are taught already at the bachelor's level they do not need to be repeated at the master's level.

1. Radioactivity, radionuclides and radiation – principles of nuclear physics to radiochemists

Aims:
To give the students the basic knowledge in nuclear physics to understand the nature of radioactivity, reasons for stability/instability of nuclides, modes of radioactive decay processes, types of radiation emitted in radioactive decay processes and the rate of radioactive decay and to acquire the skills needed to apply this knowledge.

Topics:
- structure of atom and nucleus, nucleons
- nuclides, radionuclides, isotopes, isobars, nuclide charts
- types and origin of radionuclides (natural decay series, primary primordial radionuclides, secondary natural radionuclides, cosmogenic radionuclides, artificial radionuclides, formation and occurrence)
- stability of nuclei (stable nuclides vs. radionuclides, masses on nucleons, mass deficiency, binding energy, binding energy per nucleon, proton to neutron ratio, energy valley – semiempirical equation of mass – beta parabola, fission, fusion)
- modes of radioactive decay
    - fission (process, spontaneous vs. induced, energetics, formation of fission products, fission yields, fissionable/fissile, nature of fission products)
    - alpha decay (process, energetics, alpha recoil, decay to daughter's ground state, decay to daughter's exited state, formation of alpha spectrum)
    - beta decay (processes in beta minus decay, positron decay and electron capture, energetics, beta recoil, neutrino/antineutrino, distribution of decay energy, formation of beta spectrum, beta parabola for odd/even nuclides, secondary processes (gamma decay, formation of Auger electrons and X-rays, annihilation of positrons)
    - internal transition (gamma decay, internal conversion, energetics, gamma recoil, metastable isomeric states, formation of gamma spectrum)
- rate of radioactive decay, half-life, activity units, activity concentrations vs. specific activity, activity vs. count rate, determination of half-lives, equilibria in successive decay processes
- isotopic exchange - isotope effects

2. Radiation safety

Aims:
To give the students the basic knowledge and skills on the health effects of radiation, principles of radiation safety, radiation dose and dose rate measures, measurement and calculation of radiation doses, EU and national legislation, safe practices in radionuclide laboratories and safe handling and disposal of radioactive waste from radionuclide laboratories. This topic area, including related exercises, should be completed before or in parallel with laboratory exercises with radionuclides.

Topics:
- types of radiation and their absorption processes by matter, range
- radiation safety measures and their units (absorbed dose, equivalent dose, effective dose etc.)
- effects of radiation on DNA in cells
- health effects of radiation
    - direct somatic effects
    - stochastic effects (cancer, genetic effects)
- principles of radiation safety (justification, optimization, protection of individuals)
- radiation safety organisations and their recommendations and regulations
    - EU, IAEA, ICRP
    - national authorities, laws, decrees and recommendation, licensing
- estimation and measurement of radiation doses
- radiation safety practices, safe working habits in radionuclide laboratories and with radiation sources
    - sealed sources, protection against external exposure
    - open sources, protection against internal exposure
- safe handling and disposal of radioactive waste from radionuclide laboratories
- measures during/after exceptional events

3. Detection and measurement of radiation

Aims:
To give the students basic knowledge on interaction processes of radiation with matter as a basis for radiation detection, basic instrumentation in radiation detection, detector types and formation of electric pulses in them, interpretation of various spectra, energy resolution and energy and efficiency calibrations. To give students basic skills to measure radiation with most typical radiation measurement devices, and to properly handle and evaluate the measurement data.

Topics:
- interaction processes of radiation with matter (ionization, scattering, excitation, formation of electromagnetic radiation, nuclear reaction)
    - alpha
    - beta
    - gamma
    - neutrons
- basic instrumentation in radiation measurements
- pulse counting vs. spectrometry
- pulse rate → counting efficiency → activity
- factors affecting counting efficiency (detector efficiency, absorption, geometry, self-absorption, backscattering, dead-time)

- energy resolution
- detectors for radiation measurement:
    - gas ionization detectors
    - solid and liquid scintillators
    - semiconductor detectors
- statistics and uncertainty calculations in radiometric measurements
- interpretation of gamma, alpha, beta and X-ray spectra
- energy and efficiency calibrations
- liquid scintillation counting
- radiation imaging (autoradiography, fission and alpha track counting etc)
- background formation and subtraction
- quality control in radiation measurements
- mass spectrometric measurement of radionuclides

4. Chemistry and analysis of radionuclides

Aims:
To give the students basic knowledge on the chemical properties of most important radionuclides and the chemical methods used for their separation from various matrices. To show how chemical properties and speciation affect the behaviour of radionuclides in natural and anthropogenic systems. To give the students basic skills of the chemical methods used to separate radionuclides from various matrices.

Topics:
- chemistry (oxidation states, solubilities, complex formation, hydrolysis, compounds), nuclear characteristics (half-lives, decay modes, emitted radiation) and measurement techniques of the most important radionuclides
    - natural radionuclides (e.g. U, Th, Ra, Po, Pb)
    - fission products (e.g. Cs, Sr, Tc, I, Cs etc.)
    - activation products (e.g. Ni, Fe, Co, Mn)
    - tritium and radiocarbon
    - transuranics (e.g. Np, Pu, Am, Cm)
- special characteristics of the chemistry and separations of radionuclides (trace concentrations, radiation, use of carriers, adsorption of radionuclides)
- needs and principles of radiochemical separations (alpha, beta and EC decaying radionuclides with no detectable gamma emissions, gamma emitting radionuclides of very low activities)
- analytical methods used in radionuclide separations (precipitation, ion exchange, solvent extraction, extraction chromatography)
- yield determination and counting source preparations
- separation of long-lived radionuclides for mass spectrometric measurement
- sampling and sample pretreatment methods
- speciation analysis of radionuclides
- hot-atom chemistry

5. Nuclear reactions and production of radionuclides

Aims:
To give the students basic knowledge of nuclear reactions and production of radionuclides as well as of nuclear power reactors. To give basic skills in calculation of radionuclide production yields in particle irradiations.

Topics:
- interaction processes of particles with nuclei
- types of nuclear reactions and models
- coulombic barrier
- energetics of nuclear reactions
- kinetics of nuclear reactions
- cross-sections
- excitation functions
- induced fission
- types of particle accelerators
- production of radionuclides in cyclotrons
- production of radionuclides in reactors
- radionuclide generators
- principles and uses of nuclear power reactors

6. Exercises (laboratory and calculation exercises) (at least 10 cu)

Calculation exercises:

Aims:
To give the students skills to calculate activities, their uncertainties, calculate or estimate radiation doses, calculate irradiation yields and to use nuclide chart and data bases.

Topics:
- use of nuclide chart and data bases
- calculation of activities based on half-life data, including radiochemical equilibria
- calculation of irradiation yields based on cross sections and projectile flux
- calculation of irradiation doses
- calculation of required shielding for radiation protection
- uncertainty calculation in activity measurements
- conversion of count rates to activities

Laboratory exercises:

Aims:
To give the students skills for safe handling of open and sealed radioactive sources and to safely dispose of radioactive waste from radionuclide laboratories, use of radiation dose meters and instruments to detect contamination, basic skills to detect and measure gamma and beta radiation using common radiation measurement techniques and to separate radionuclides from aqueous and solid samples using common radiochemical separation methods.

Topics:
- detection of surface contamination for radiation safety
- use of radiation dose meters for radiation safety to measure total dose and dose rates
- measurement of radiation with a simple detector, such as Geiger tube (e.g. dead-time, absorption of beta radiation, counting geometry etc.)
- measurement of radiation with a LSC
- measurement of radiation with a gamma spectrometer - energy calibration, interpretation of gamma spectra

- separations of radionuclides using various methods, such as precipitation/coprecipitation, ion exchange chromatography, solvent extraction and/or extraction chromatography

Recommended laboratory exercises:

Below a more comprehensive list of laboratory exercises is given as a recommendation.
- detection of planar contamination for radiation safety
- use of radiation dose meters for radiation safety to measure total dose and dose rates
- measurement of radiation with a Geiger tube (e.g. determination of absorption curve for beta radiation, determination of dead-time, effect of counting geometry on observed counting efficiency)
- determination of half-life (determination of the half-life of a short-lived radionuclide, such as^{137m}Ba, obtained from a generator)
- single channel exercise with a solid scintillation detector (measurement of the gamma spectrum of a gamma emitting radionuclide, such as ^{137}Cs, measurement of a standard and an unknown sample on the selected peak region, calculation of the activity of the unknown sample, determination of energy resolution)
- gamma spectrometry with a solid scintillation detector (energy calibration, determination of a sample containing few unknown radionuclides, identification of these radionuclides, interpretation of the gamma spectrum)
- gamma spectrometry with a semiconductor detector (energy calibration, determination of a sample containing unknown radionuclides, identification of these radionuclides, interpretation of the gamma spectrum)
- alpha spectrometry (separation of an alpha emitter from environmental or waste sample using radiochemical separation techniques, preparation of the counting source, measurement of the alpha spectrum, calculation of the activity)
- beta counting with LSC (quenching curve determination, separation of a beta emitter from environmental or waste sample using radiochemical separation techniques, preparation of the counting source, measurement of the sample for the activity determination)
- practice in working behind shielding or in a glove box, is possible with higher levels of activity
- synthesis of a radiolabelled compound
- radiochemical separations using precipitation, ion exchange, solvent extraction and extraction chromatography
    - separation of beta emitting radionuclides (e.g. ^{90}Sr)
    - separation of alpha emitting radionuclides (e.g. ^{234,235,238}U)
    - separation of EC decaying radionuclides (e.g. ^{55}Fe)

2.2.4 Optional studies (minimum 10 cu):

Optional studies consist of several modules on various application fields of nuclear and radiochemistry. Examples of such modules are given below. The fields of the courses are recommended to closely link with the actual research field/s of the unit giving the teaching so that the teaching and research are closely connected and best available researchers are giving the courses at their specialty areas. If possible, the courses may also contain laboratory exercises.

7. Chemistry of the nuclear fuel cycle

Topics:
- uranium ores

- extraction of uranium from ore minerals
- mill tailings and their disposal
- purification of raw uranium products
- enrichment of ^{235}U
- production of uranium fuel for power reactors
- use on uranium fuel in power reactors
- power reactor types
- water chemistry of nuclear power reactors
- types of nuclear waste and their formation processes
- management and final disposal of nuclear waste
- reprocessing of spent nuclear fuel
- decommissioning of nuclear facilitities
- behaviour of nuclear waste in geological final repositories

8. Radiopharmaceutical chemistry

Topics:

- production of radionuclides
    - in cyclotrons
    - in nuclear reactor
    - with radionuclide generators
    - radionuclidic purity
    - target chemistry
- radiopharmaceutical chemistry
    - types of organic molecules and other compounds to be labeled
    - labeling chemistry of ^{11}C
    - labeling chemistry of ^{18}F
    - radioiodinations (^{123}I and ^{124}I)
    - labeling chemistry of metal radionuclides (^{68}Ga, ^{111}In, ^{64}Cu, ^{99m}Tc)
    - radiochemical purity
- quality control and regulatory issues
- PET and SPECT imaging
    - instrumentation
    - pharmacokinetics and modeling
- applications in
    - diagnostics (oncology, cardiology, neurology and psychiatry, gene expression and cell trafficking)
    - drug development
    - medical research
    - therapeutics

9. Environmental radioactivity – radioecology

Topics:

- description of environmental compartments (geosphere, biosphere, atmosphere)
- sources of radionuclides in the environment
    - natural
    - artificial
- behaviour of radionuclides in
    - the air
    - natural waters
    - soils and sediments

    - biota
- speciation and tracer techniques
- mobility and bioavailability studies
- environmental impact and risk assessment
- transfer processes of radionuclides in the environment and in food chains
- modelling of transfer processes
- countermeasures and preparedness

10. Chemistry of actinides and transactinides

Topics:

- natural actinides
- production/formation of actinides in nuclear explosions, nuclear reactors and accelerators
- electronic structure
- ionic radii
- oxidation state
- major chemical forms
- disproportionation
- hydrolysis and polymerisation
- complex formation
- oxides and other important compounds
- chemistry of U, Th, Np, Pu and Am
- speciation of actinides
- separations
    - analytical
    - industrial (PUREX etc)
- production of transactinides - extension of the periodic table
- chemical properties of the transactinides

11. Chemistry of radionuclides in geosphere related to final disposal of spent nuclear fuel or high-level waste

Topics:

- management of spent nuclear fuel (SNF)
- reprocessing of nuclear fuel, production of high-level waste (HLW)
- encapsulation of SNF/HLW
- geological disposal of SNF/HLW
- dissolution/leaching of radionuclides from SNF/HLW
- forms of radionuclides in SNF/HLW
- forms of dissolved radionuclides in the repository environment
- analytical methods for radionuclide speciation
- functions and long-term behaviour of buffer materials (e.g. bentonite)
- migration of radionuclides in geosphere
- sorption of radionuclides in minerals
- diffusion of radionuclides into geological matrix

11. Radiation chemistry

Topics:

- Irradiation methods

  - Types of irradiation sources and devices
  - Dosimetrics
  - Effects of irradiation geometry, thickness of the target etc.
  - Use of data basis and related computer programmes
- Reactions in radiation chemistry in various materials
  - Basic reactions, formation of intermediates, excited states, ions, electrons and radicals
  - Reaction of intermediates, formation of stable products
  - Radiation chemical yields
  - Kinetics of radiolysis
  - Reactions in water and water solutions, polymers, metals, nuclear fuel, nutrients, cells etc.
- Analytical methods used in radiation chemistry
- Application of radiation chemistry
  - radiation sterilization of medical equipment
  - radiation sterilization of food stuffs
  - polymerization and polymer functionalization
  - etc.

12. Nuclear and radioanalytical methods

Topics:

- Radioimmunoassay (RIA)
- Neutron activation analysis (NAA) – instrumental and radiochemical
- Isotope dilution analysis
- Radiodating methods (^{14}C-dating, ^{210}Po-dating etc.)
- Radiometric titration
- Use of nuclear and radioanalytical methods in industry

3 CONCLUSIONS

The minimum requirements for NRC EuroMaster's degree were defined. Master's program eligible to NRC Euromaster should have at least 50% (60 cu) of its master's studies on nuclear and radiochemistry. Of these 60 credit units at least 10 credit units should be practical exercises and at least 30 credit units should comprise of master's thesis and project work. The educational program should cover most relevant aspects from the following five topic areas - Radioactivity, radionuclides and radiation - Radiation safety - Detection and measurement of radiation - Chemistry and analysis of radionuclides - Nuclear reactions and production of radionuclides.