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DELIVERABLE D3.3

Report on available teaching resources and future needs

Lead Beneficiary: Chalmers

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EXECUTIVE SUMMARY

As described in the project, during and thanks to the CINCH projects series, many courses have been gathered, updated and designed. The amount of data is significant and has been kept in different formats on different open-source platforms, under CINCH umbrella.

In some cases, they are not easy to be used or reached, especially for those who are not members of the project or partnership.

In agreement with the call addressing the potential loss of knowledge, the effort in the Task 3.2 is to design the way to spread the created knowledge, releasing and sharing teaching and learning materials as Open Educational Resources and Practices (OER).

For this task to be able to be fulfilled, a series of preparatory tasks are needed, highlighted in this deliverable, D3.3 **Report on available teaching resources and future needs**.

In order to be able to prepare for the future, one needs to look at the past and present status of the project, thus **a look back at the inventories** carried-out in the beginning of CINCH projects, updated several times since, of the teaching curricula of NRC in Europe (and Russia) was done for identifying the missing or not sufficiently developed materials, in order to identify the future needs for the CINCH project teaching inventory. The results are presented below.

CONTENT

1 INTRODUCTION

One of the current main concerns in the nuclear sector, according to EURATOM Work Programme 2019-2020 Nuclear Fission and Radiation Protection Research of its NFRP-2019- 2020-11 is a loss of interest in specialized nuclear knowledge among the younger generation, as well as the risk that the current workforce, which is gradually retiring, will not be replaced. Regardless of the EU's nuclear power sector, highly educated personnel with very specific knowledge, skills, and competencies will continue to be required in the future. The unique skill-based impairments within nuclear chemistry were identified in early follow-up investigations as one of the disciplines most concerned with the risks stated above.

Among other things, the A-CINCH proposal addresses the need to address the shortage of skill-based knowledge in the field of nuclear chemistry. Many courses have been designed as a result of the CINCH project series. They can be difficult to use in some situations, especially for individuals who are not members of the partnership. Following the call to address the risk of knowledge loss, the goal of this task will be to design a method for disseminating newly created knowledge by releasing and sharing teaching and learning materials as Open Educational Resources and Practices (OER) and to raise NRC awareness at various levels of understanding.

This report presents the gap analysis carried on by CHALMERS required for both existing and developing resources, to determine the integrity of the contents provided thus far as well as their accessibility for users.

In order to be able to prepare for the future, one needs to look at the past and present status of the project, thus two main actions have been conducted:

1. First of all, **a gap analysis** (CHALMERS), intended to address proper actions to be taken, is necessary for the existing materials as well as the materials being developed: to look at the integrity of the materials provided so far as well as their accessibility for the users. This activity is also related to the possibility to release of the Open Educational Resources and Practices (OER) and to the T3.5 “Organize, expand, promote and maintain NucWik” activity, because NucWik will be the main platform dedicated to publishing and sharing the OER materials.
2. **A look back at the inventories** carried-out in the beginning of CINCH project, updated several times since, of the teaching curricula of NRC in Europe (and Russia) for identifying the missing or not sufficiently developed materials, in order to identify the future needs for the CINCH project teaching inventory.

2 GAP ANALYSIS

A gap analysis is a method of evaluating performance disparities in a "business" information system or identifying whether "business" requirements are being fulfilled and, if not, what efforts should be made to ensure they are met successfully. *Gap* refers to the space between the current state and the target state.
Organizations could use a gap analysis approach to figure out how to effectively achieve their business objectives. It contrasts the current state with the desired state or set of goals, highlighting flaws and areas for improvement.

2.1 GAP analysis of the A-CINCH project

The Gap analysis performed as part of Task 3.2 of the A-CINCH project focuses on the evaluation of the open educational resources created within the project to identify the flaws and areas for improvement.
The open resources can be found in https://www.cinch-project.eu/links.
The first source of content to be included in the Gap analysis is the NucWik (NUClear and Radiochemistry Teaching Material WIKi) database composed of exercises and textbooks.
For this Gap analysis, an excel file was built for the evaluations of the different exercises. In the excel the source of the exercise (data) to be evaluated; the general description of the data; the date checked; the copyright of the lab of exercise; the corresponding institution in charge of the data; the year posted; if there are some issues with the data in each case; the reason for that issue (if the data is missing; inaccessible; if there is an error or the data are incomplete; if the sources of the data are missing or there is an inappropriate use of them.) and finally some comments and recommendations to make it easier to find the errors or faults are indicated and summarized.
In Figure 1, an example of the excel sheet can be seen where all the tags are present and some examples of the first exercises (RoboLab of the NucWik database).
In the ANNEXE I the complete excel is presented with the identification of the problematic point of the NucWik open source.

DATA SOURCE	GENERAL DESCRIPTION	Date checked	COPYRIGHT	INSTITUTION	YEAR	ISSUE	REASON	COMMENTS & RECOMENDATIONS
NUCWIK RoboLab	Robolab Exercise - Absorption and Detection of Gamma-Radiation	2021-04-15	Jon Petter Omtvedt (UiO)	Department of Chemistry, University of Oslo, Norway	2018	The webpage is not working	INACCESSIBLE	The run link of the exercise in the robolab is not working
Nucwik RoboLab	Robolab procedure for absorption of γ-radiation	2021-04-15	Jon Petter Omtvedt (UiO)	Department of Chemistry, University of Oslo, Norway	2018	the source of the figure is not specify	SOURCE MISSING	the screen shot of the program is located ON the text.
NUCWIK RoboLab	Absorption of Gamma Radiation and Analysing the Data	2021-04-15	Jon Petter Omtvedt (UiO)	Department of Chemistry, University of Oslo, Norway	2018	Student guidelines	MISSING	Some of the student guideline are missing such as Absorption of Gamma Radiation (to be written); Analysing the Data (to be written); General theory on absorption of radiation (from NucWik NRC textbook)
Nucwik RoboLab	Absorption of Gamma Radiation and Analysing the Data	2021-04-15	Jon Petter Omtvedt (UiO)	Department of Chemistry, University of Oslo, Norway	2018	Teacher Guides	MISSING	The Teacher Guides are missing such as About learning benefits from this exercise; How to prepare for using this exercise and Notes on methods for analysing the data.
NUCWIK RoboLab	Robolab Exercise - Neutron Activation of Silver	2021-04-20	Jon Petter Omtvedt (UiO)	Department of Chemistry, University of Oslo, Norway	2018	"We plan to have the exercise available in the new version by the end of May 2020"	INCOMPLETE	The exercise is under upgraded

Figure 1: Gap analysis excel for the first database NucWik.

The continuation of the Gap analysis includes the evaluation of the CINCH Moodle. As part of the CINCH-II project, this platform was built to provide some nuclear chemistry courses to mitigate the lack of qualified people in the nuclear field. This part of the analysis was different from the previous one. The excel field comprises an inventory of the courses. The main tags are the Cinch Moodle: Course categories; Course subcategories; the copyright and the year of the course, as well as the date of the check. The last tags of the analysis are dedicated if there is any error, inaccessible data, or a broken link in the course's material. If the information is not complete in excel means that the info is missing and/or there are no flaws in the data in those courses/websites.

In Figure 2 an example of the courses inventory is depicted, where the tags are shown as explained previously.

The complete inventory of the CINCH Moodle is in ANNEXE II.

SOURCE	Cinch Moodle: Course categories	Course sub_categories	COURSE	Date checked	COPYRIGHT	INSTITUTION	YEAR	ISSUE	COMMENTS & RECOMENDATIONS
CINCH: Cooperation in Education in Nuclear ChemistrySeventh Framework Programme. Euratom (Euratom Fission Training Scheme)	moodle.cinch-project.eu								
		Hands-on Training	Hands on Training in Radioanalytical Methods	2021-06-16	Ms. Štěpánka Maliňáková (malinakova@fjfi.cvut.cz)	Czech Technical University in Prague	Feb 3-7, 2020	INACCESSIBLE	sources. CHAPTER 5: Radiation Safety and Health Hazards but it is hidden from the students.
			Hands-on Training in Nuclear Chemistry III 2018	2021-06-16	Ms. Štěpánka Maliňáková (malinakova@fjfi.cvut.cz)	Czech Technical University in Prague	Jun 18-22, 2018	INACCESSIBLE	There are broken links: - Instructions what to take to the practical exercises and hidden for the students. - Optional materials. CHAPTER 5: Radiation Safety and Health Hazards
			Hands-on Training in Separation Methods in Radiochemistry	2021-06-16	-	Czech Technical University in Prague	-	-	-
			Practical Exercises in Radioanalytical Methods (original course)	2021-06-16	-	Czech Technical University in Prague	-	-	-
			HoT RAM test copy 1	2021-06-16	Ms. Štěpánka Maliňáková (malinakova@fjfi.cvut.cz)	Czech Technical University in Prague	Feb 3-7, 2020	INACCESSIBLE	sources. CHAPTER 5: Radiation Safety and Health Hazards but it is hidden from the students.
			Hands on Training in Nuclear Chemistry II old_backup 2018	2021-06-16	Ms. Štěpánka Maliňáková (malinakova@fjfi.cvut.cz)	Czech Technical University in Prague	Jan 11-14, 2016	INACCESSIBLE	CHAPTER 5: Radiation Safety and Health Hazards
			Hands on Training in Nuclear Chemistry II old_original_v1	2021-06-16	Ms. Štěpánka Maliňáková (malinakova@fjfi.cvut.cz)	Czech Technical University in Prague	Jan 11-14, 2016	INACCESSIBLE	There is a broken link in the optional materials. CHAPTER 5: Radiation Safety and Health Hazards. - there are some parts imcomplete
	Learning and Training Courses		Measurements of tritium and C-14	2021-06-16	-	-	2020	-	-
			Basics of Analytical Radiochemistry	2021-06-17	-	-	2020	-	-

Figure 2: CINCH Moodle inventory example as part of the Gap analysis.

2.2 A look back at the inventories

In the first CINCH project, two deliverables were dedicated to the **Nuclear and radiochemistry curricula in the European universities (D 1.1 – LUH)** and **Teaching Radiochemistry in Russia (D1.2 – MSU).** In these deliverables, teaching curricula were divided:

in Europe:

-BsC courses and MSc courses *General nuclear and radiochemistry*

- *Environmental radiochemistry and radioecology*

- *Miscellaneous specializations* as well as the role of e-learning at that time.

and in Russia:

- basic courses,

- special courses.

The survey of NRC curricula in Europe was gathered from 22 countries and 69 universities. The majority of these universities had NRC education both at BSc and MSc level; in addition, PhD work under related fields were identified. A total 247 PhD projects were described in the 42 filled questionnaires.

At BSc level NRC was mainly taught in basic courses under various educational programs such as chemistry or environmental sciences. The number of students attending these courses was relatively high, average 40 in each course. There were only few complete programs i.e. BSc/MSc degrees in NRC; however, education in the same extent could be attained in various specializations under e.g. the degrees MSc in Chemistry or Chemical/Environmental engineering. Research training and diploma work have a strong role in specialization, though the extent of specialization varies in different educational systems.

Altogether, 44 educational programs (degree and/or specialization) in 30 different universities were described. However, average number of students graduating annually from these programs is typically 5 or even less. Majority of the specializations are under general nuclear and/or radiochemistry, large specified topic is environmental radiochemistry and/or radioecology. In general, curriculum in NRC reflects research interests of the department.

And update of the survey in the CINCH-II project (**D1.5 Updated report on NRC curricula in European universities – LUH**) had shown a clear decline in both the number of courses and universities which still had programs with regards to NRC teaching. The curricula remained almost the same in Europe, with an increased trend in **Decommissioning** and **Disposal** courses.

The survey in Russia has also been updated in the same deliverable.

In CINCH-II project, another deliverable has been developed and published, as effort to help the NRC education, namely **D1.4 Recommendation of NRC textbooks to universities.**

Even more, in order to understand the requirements of the non-academic end-users, a review of the training requirements of the end users was conducted as well in CINCH-II.

As a result of these studies, a comprehensive list of identified minimum requirements for a master/teaching/training in Nuclear Chemistry has been compiled and is transcribed here, as part of a Euro-Master course.

For the sake of simplification, only the curricula will be given below, in order to help identify the missing or not enough developed materials in CINCH project series (future needs):

EU project CINCH II (Cooperation in education in nuclear chemistry) - https://www.cinch-project.eu/cinch2/

In the following, minimum requirements for nuclear and radiochemistry education in the European universities are layed out for MSc level. The plan describes the content and structure of Euromaster in NRC degree.

Compulsory studies on nuclear and radiochemistry (25 cu)

In the following, topic areas (1-6) and 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.

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

Aims:
To teach NRC students the basic knowledge in nuclear physics in order 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.

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
- principles and uses of nuclear power reactors.

2. Radiation safety

Aims:
To teach the students the basic knowledge on the health effects of radiation, principles of radiation safety, radiation dose and dose rate measures, estimation and calculation of radiation doses, EU and national legislation, safe practices in radionuclide laboratories and safe handling and disposal of radioactive waste from radionuclides laboratories. This topic area, including related exercises, should be completed before the students are allowed to do 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 teach 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, energy and efficiency calibrations. Since ICP-MS is becoming a standard method for the measurement of many radionuclides basics on mass spectrometric measurement of radionuclides should also be at least shortly covered.

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 (detector, preamplifier, amplifier, ADC, MCA)
- 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 error 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 teach basic knowledge on the chemical properties of most important radionuclides and the chemical methods used for their separation from various matrices. To teach how chemical properties and speciation affect the behaviour of radionuclides in natural and anthropogenic systems.

Topics:

- chemistry (oxidation states, solubilities, complex formation, hydrolysis, compounds), nuclear characteristics (half-lives, decay modes, emitted radiation), measurement

techniques of most important alpha and beta emitting radionuclides in the environment and in nuclear waste
    - natural radionuclides (U, Th, Ra, Po, Pb)
    - fission products (Sr, Tc, I, Cs etc.)
    - activation products (Ni, Fe, Co, Mn)
    - tritium and radiocarbon
    - transuranics (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 teach the students basic knowledge on nuclear reactions and production of radionuclides. This topic area also gives 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.

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

<u>Calculation exercises:</u>

Aims:
To give the students skills to calculate activities, their uncertainties, calculate or estimate radiation doses, calculate irradiation yields and to use nuclide charts / tables of nuclides.

Topics:
- use of internet nuclide chart / table of nuclides
- calculation of activities based on half-life data
- calculations of irradiation yields based of cross sections and projectile flux
- calculation and measurement of gamma irradiation dose from a point source
- calculation of required shielding for radiation protection
- uncertainty calculations in activity measurements
- conversion of count rates to activities.

<u>Laboratory exercises:</u>

Aims:
To give the students skills for safe handling of radionuclides and sealed 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 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 (absorption of beta radiation etc)
- measurement of radiation with a LSC
- measurement of radiation with a gamma spectrometer - interpretation of gamma spectra
- separations of radionuclides by using
    - 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)
- 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).

Optional studies (minimum 5 cu):

Optional studies consist of several modules on various application fields of nuclear and radiochemistry. Examples of such modules are given below. The minimum extent of a course should be 5 cu. 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.

As an overall conclusion of the above-presented analysis, the de-facto implementation of the findings of the CINCH-I and CINCH-II projects has started already in the CINCH-II project, while new methods, more explicitly the base of the current A-CINCH project, has started in the MEET-CINCH project: the e-training sessions with the first implementation of mixed e-learning and hands-on learning, switched class sessions and so-called RoboLabs set-up have been tested and currently updated and used.

In A-CINCH, one further leap is taken into the fast development of technology and switch in paradigm teaching (also due to the global CORONA-19 pandemic situation): virtual reality training and teaching at university level, which in some industries was already implemented with moderate success even before this period. However, at the university level, the need for flexibility in space and time for teaching methods have been proven to be lacking this part until now.

2.3 Future needs identification

Thinking of the above-mentioned gaps and findings, one can elaborate a list of future needs identified, at macro-level:

- The urgent need of a unified platform, with a sole entrance-point to access all the information produced by the CINCH projects to date.
- The need to store and have rules of accessibility for: surveys and past available data for NRC as well as the possibility for updates.
- The need to store and have rules of accessibility for: teachers and students to the produced material, in a sustainable way for the platform.
- The urgent need for a plan for maintenance and conversion of materials to more accessible interfaces and current teaching platforms. The development in the last 2 years have been very fast, development which otherwise would have been taking some additional years until implementation.
- The urgent need for a plan for update and improvement of presentation techniques of older materials (the content has already been checked and approved of CINCH project).
- The urgent need to add teaching material with regards to Decommissioning and Disposal adapted to the current need in Europe (and the world), where the old fleet of reactors is slowly closed and planned for removal.

- The urgent need to add material for new technologies which are driven by other type of neutron spectra and materials (GEN IV, modular reactors).
- The urgent need to plan and implement a permanent custodian's group of the unified platform, or similar, to allow continuity and growth.

3 CONCLUSIONS

In order to be able to prepare for the future, one needs to look at the past and present status of the project, thus two main actions have been conducted - a gap analysis and evaluation of the inventories and result carried-out in the beginning of the CINCH project. All the findings were summarized in the Excel sheet. The list has been shared with A-CINCH community and the current custodians of the materials overviewed. The materials have not been reviewed by Chalmers, who only checked the integrity of the materials, it is expected that the owners of the materials or source terms will be able to restore all the functions.

Future needs were identified resulting in the list of recommendations and urgent needs to be done, reflected or implemented, as it is itemized in the Chapter 2.3.

ANNEX 1

DATA SOURCE	GENERAL DESCRIPTION	Date checked	COPYRIGHT	INSTITUTION	YEAR	ISSUE	REASON	COMMENTS & RECOMENDATIONS
NUCWIK_RoboLab	Robolab Exercise - Absorption and Detection of Gamma-Radiation	2021-04-15	Jon Petter Omtvedt (UiO)	Department of Chemistry, University of Oslo, Norway	2018	The webpage is not working	INACCESSIBLE	The run link of the exercise in the robolab is not working
Nucwik_RoboLab	Robolab procedure for absorption of γ-radiation	2021-04-15	Jon Petter Omtvedt (UiO)	Department of Chemistry, University of Oslo, Norway	2018	the source of the figure is not specify	SOURCE MISSING	the screen shot of the program is located ON the text.
NUCWIK_RoboLab	Absorption of Gamma Radiation and Analysing the Data	2021-04-15	Jon Petter Omtvedt (UiO)	Department of Chemistry, University of Oslo, Norway	2018	Student guidelines	MISSING	Some of the student guideline are missing such as Absorption of Gamma Radiation (to be written); Analysing the Data (to be written); General theory on absorption of radiation (from NucWik NRC textbook)
Nucwik_RoboLab	Absorption of Gamma Radiation and Analysing the Data	2021-04-15	Jon Petter Omtvedt (UiO)	Department of Chemistry, University of Oslo, Norway	2018	Teacher Guides	MISSING	The Teacher Guides are missing such as About learning benefits from this exercise; How to prepare for using this exercise and Notes on methods for analysing the data.
NUCWIK_RoboLab	Robolab Exercise - Neutron Activation of Silver	2021-04-20	Jon Petter Omtvedt (UiO)	Department of Chemistry, University of Oslo, Norway	2018	"We plan to have the exercise available in the new version by the end of May 2020"	INCOMPLETE	The exercise is under upgraded
NUCWIK_RoboLab	Robolab Exercise - Neutron Activation of Silver	2021-04-20	Jon Petter Omtvedt (UiO)	Department of Chemistry, University of Oslo, Norway	2018	Source of the pictures	INCOMPLETE	The source (copyright) is printed in the figures so it is not easy to see, it could be also outside where it can be seen better.
NUCWIK_RoboLab	RoboLab Remote Controlled Experiments	2021-04-21	–	Institute for Radiation Protection and Radioecology (IRS) at the Leibniz University of Hanover and at the Nuclear Chemistry Section at Department of Chemistry, University of Oslo (UiO)	2018	RoboLab experiments incomplete	INCOMPLETE	The experiments RL3-RL6 are not included in the website
NUCWIK_Laboratory	Lab Exercise - Basic Laboratory Procedures for Radiochemistry	2021-04-21	–	Section of Radiochemistry. Institute of Chemistry. Faculty of Mathematics and Natural sciences. University of Oslo	?	Lab Procedures	INCOMPLETE	Missing the Safety Aspects; Equipment; and Preparation for the lab Supervisor tabs
NUCWIK Laboratory	Lab Exercise - Preparation of Counting Samples	2021-04-26	Missing	Missing	?	Lab Procedures	INCOMPLETE	Missing: theory and copyright
NUCWIK_laboratory	Laboratory Exercises	2021-04-26	Depends on the training or exercises	Depends on the training or exercises	?	Laboratory Exercises	INCOMPLETE	Some of the training, Detection Methods and Equipment and other exercises are missing
NUCWIK_laboratory-exercises	Lab Exercise - LSC Principles	2021-04-26	Jon Petter Omtvedt & Tor Bjørnstad	Nuclear Chemistry Group. Department of Chemistry, University of Oslo, Norway	?	Theory: LSC Principles	ERROR	One of the figure is missplaced on the tet

DATA SOURCE	GENERAL DESCRIPTION	Date checked	COPYRIGHT	INSTITUTION	YEAR	ISSUE	REASON	COMMENTS & RECOMENDATIONS
Nucwik_laboratory-exercises	Lab Exercise - Interfering Processes	2021-04-26	Jon Petter Omtvedt & Tor Bjørnstad	Nuclear Chemistry Group. Department of Chemistry, University of Oslo,	?	Theory	ERROR	Some figures and one euation are missplaced on the tet
Nucwik_laboratory-exercises	Lab Exercise - Liquid Scintillation Counting	2021-04-26	Jon Petter Omtvedt & Tor Bjørnstad	Nuclear Chemistry Group. Department of Chemistry, University of Oslo, Norway	?	Lab Procedures	MISSING	The Question for the student. That part is to be completed by the teacher in each case or it is missing this section. If it is up to the teacher in each case, it could be written
Nucwik_laboratory-exercises	Lab Exercise - Measurement of Isotopes Using čerenkov	2021-04-26	–	Center for Radiochemistry and Nuclear Materials. Loughborough	?	Lab Procedures	INCOMPLETE	Some of the tab in the procedures are incomplete such as euipment or preparation
Nucwik_laboratory-exercises	Lab Exercise - Neutron Activation Analysis	2021-04-26	Missing	Missing	?	Copyright	MISSING	The copyright in this exercise is missing. There is no Developed by
Nucwik_laboratory-exercises	Lab Exercise - Neutron Activation Analysis	2021-04-26	Missing	Missing	?	Lab Procedures	INCOMPLETE	**Missing**: Equipment
Nucwik_laboratory-exercises	Lab Exercise - Neutron Activation of Silver and two Component Decay	2021-04-27	–	Section of Radiochemistry. Institute of Chemistry. Faculty of Mathematics and Natural sciences. University of	?	Lab Procedures	INCOMPLETE	The page is under construction
Nucwik_laboratory-exercises	Lab Exercise - Uranium-oxide Calibration Standard for GM-tubes	2021-04-27	–	Section of Radiochemistry. Institute of Chemistry. Faculty of Mathematics and Natural sciences. University of	?	Lab Procedures	INCOMPLETE	missing parts: - theory links; fiure 1
Nucwik_laboratory-exercises	Lab Exercise - Szilard-Chalmers Method	2021-04-27		CHALMERS???	?	Lab Procedures	MISSING	All the lab procedure is missing
Nucwik_laboratory-exercises	Lab Exercise - Isotope-Dilution Analysis	2021-04-27	Missing	Missing	?	Lab Procedures	MISSING	All the lab procedure is missing
Nucwik_laboratory-exercises	Lab Exercise - Determination of ^{55}Fe **in Nuclear Waste**	2021-04-27	–	Laboratory of Radiochemistry. Department of Chemistry. University of Helsinki. Finland	?	Lab Procedures	INCOMPLETE	imcomplete the Equipment and Safety Aspects
Nucwik_simulation_exercises	Student Guide to a Computer Program which Simulate Gamma-ray Detection	2021-04-29	Jon Petter Omtvedt (UiO)	Department of Chemistry, University of Oslo, Norway	?	Theory	ERROR	One of the figure is missplaced on the tet
Nucwik_textbooks	Interaction Between Radiation and Matter	2021-04-29	Copied without editing from NucWik WikiSpaces site	–	?	Theory	INCOMPLETE	In the text it is mentioned some figures that do not appear. Also it is not clear the source of the text.
Nucwik_Calculation exercises	Calculation Exercises	2021-04-29	–	–	?	Solutions	MISSING	The solutions for the Exercises with Particles and Nuclear Reactions are missing
Nucwik_laboratory-exercises	Laboratory Exercises- Radiation Protection Training	2021-04-30	–	–	?	Laboratory Exercises	INCOMPLETE	The Skin contamination tab is missing in the radiation protection training.
Nucwik_laboratory-exercises	Laboratory Exercises- Detection Methods and Equipment	2021-04-30	–	–	?	Laboratory Exercises	INCOMPLETE	The gamma spectroscopy and the basic use and calibration of GM-detector exercises are missing
Nucwik_laboratory-exercises	Laboratory Exercises- Other Type of Exercises	2021-04-30	–	–	?	Laboratory Exercises	INCOMPLETE	There are missing 6 of the exercises propoused in the other type of exercises tab.
Nucwik_lab-exercises	Lab Exercise - Basic Laboratory Procedures for Radiochemistry	2021-04-30	–	Section of Radiochemistry. Institute of Chemistry. Faculty of Mathematics and Natural sciences. University of	?	Lab Exercise	MISSING	The euipment and preparation for the lab supervisor are missing in the lab procedure.
Nucwik_lab-exercises	Lab Exercise - Preparation of Counting Samples	2021-04-30	–	–	?	Lab Procedures	MISSING	The copyright in this exercise is missing. There is no Developed by
Nucwik_lab-exercises	Lab Exercise - Liquid Scintillation Counting	2021-04-30	Jon Petter Omtvedt & Tor Bjørnstad	Nuclear Chemistry Group. Department of Chemistry, University of Oslo,	?	Lab Procedures	INCOMPLETE	The uestions for the students are missing.
Nucwik_lab-exercises	Lab Exercise - LSC Principles	2021-05-03	Jon Petter Omtvedt & Tor Bjørnstad	Nuclear Chemistry Group. Department of Chemistry, University of Oslo,	?	Theory	ERROR	The figure 4 is missplace on the text and is missing the caption

DATA SOURCE	GENERAL DESCRIPTION	Date checked	COPYRIGHT	INSTITUTION	YEAR	ISSUE	REASON	COMMENTS & RECOMENDATIONS
Nucwik_lab-exercises	Lab Exercise - Interfering Processes	2021-05-03	Jon Petter Omtvedt & Tor Bjørnstad	Nuclear Chemistry Group. Department of Chemistry, University of Oslo,	?	Theory	ERROR	Figures 2-4 are missplaced on the text and the equation 9 is on the text.
Nucwik_lab-exercises	Lab Exercise - Quench Corrections in Liquid Scintillation	2021-05-03	_	Center for Radiochemistry and Nuclear Materials. Loughborough	?	Lab Procedures	MISSING	Figure 2 is missing in the text
Nucwik_lab-exercises	Lab Exercise - Introduction to Neutron Activation Analysis	2021-05-03	_	Center for Radiochemistry and Nuclear Materials. Loughborough	?	Theory	ERROR	Figure 3 and are misplaced on the text and all the euations of the text
Nucwik_lab-exercises	Lab Exercise - Neutron Activation of Silver and two Component Decay	2021-05-03	_	Section of Radiochemistry. Institute of Chemistry. Faculty of Mathematics and Natural sciences. University of	?	Lab Procedures	INCOMPLETE	Under construction
Nucwik_lab-exercises	Lab Exercise - Uranium-oxide Calibration Standard for GM-tubes	2021-05-03	_	Section of Radiochemistry. Institute of Chemistry. Faculty of Mathematics and Natural sciences. University of	?	Lab Procedures	INCOMPLETE	The theory links are missing. The Figure 1 is also missing
Nucwik_lab-exercises	Lab Exercise - Szilard-Chalmers Method	2021-05-03	_	_	?	Lab Procedures	INCOMPLETE	Under construction
Nucwik_lab-exercises	Lab Exercise - Isotope-Dilution Analysis	2021-05-03	_	_	?	Lab Procedures	INCOMPLETE	Under construction
Nucwik_lab-exercises	Lab Exercise - Determination of ^{55}Fe in Nuclear Waste	2021-05-03	_	Laboratory of Radiochemistry. Department of Chemistry. University of Helsinki. Finland	?	Lab Procedures	MISSING	Missing the equipment and the safety aspects
Nucwik_lectures	Recorded Lectures or Lecture Material	2021-05-03	_	_	?	Lectures	INCOMPLETE	There are no links to the on-line lectures

ANNEX 2

SOURCE	Cinch Moodle: Course categories	Course sub_categories	COURSE	Date checked	COPYRIGHT/Teacher	YEAR	ISSUE	COMMENTS & RECOMENDATIONS
CINCH: Cooperation in Education in Nuclear ChemistrySeventh Framework Programme. Euratom (Euratom Fission Training Scheme)	moodle.cinch-project.eu							
	Learning and Training Courses	Hands-on Training	Hands on Training in Radioanalytical Methods	2021-06-16	Pavel Bartl,Tomas BilyTomas, Cechak,Katerina Cubova, et al.	Feb 3-7, 2020	INACCESSIBLE	sources. CHAPTER 5: Radiation Safety and Health Hazards but it is hidden from the students.
			Hands-on Training in Nuclear Chemistry III 2018	2021-06-16	Nick Evans	Jun 18-22, 2018	INACCESSIBLE	There are broken links: - Instructions what to take to the practical exercises and hidden for the students. - Optional materials. CHAPTER 5: Radiation Safety and Health Hazards
			Hands-on Training in Separation Methods in Radiochemistry	2021-06-16	-	-	-	-
			Practical Exercises in Radioanalytical Methods (original course)	2021-06-16	-	-	-	-
			HoT RAM test copy 1	2021-06-16	Ms. Štěpánka Maliňáková (malinakova@fjfi.cvut.cz)	Feb 3-7, 2020	INACCESSIBLE	sources. CHAPTER 5: Radiation Safety and Health Hazards but it is hidden from the students.
			Hands on Training in Nuclear Chemistry II old_backup 2018	2021-06-16	Ms. Štěpánka Maliňáková (malinakova@fjfi.cvut.cz)	Jan 11-14, 2016	INACCESSIBLE	CHAPTER 5: Radiation Safety and Health Hazards
			Hands on Training in Nuclear Chemistry II old_original_v1	2021-06-16	Ms. Štěpánka Maliňáková (malinakova@fjfi.cvut.cz)	Jan 11-14, 2016	INACCESSIBLE	There is a broken link in the optional materials. CHAPTER 5: Radiation Safety and Health Hazards. - there are some parts imcomplete
		Detection and detemination of radionuclides	Measurements of tritium and C-14	2021-06-16	Matjal Koleli and Marko Štrok	2020	-	-
			Basics of Analytical Radiochemistry	2021-06-17	Ljudmila Benedik and Marko Štrok	2020	-	-
			Gamma-spectrometric investigation of Cs-134 in a soil sample from Fukushima	2021-06-17	-	2020	-	-
			Gamma spectrometric analysis of Chernobyl and Fukushima samples	2021-06-17	-	2020	-	-
			GammaLab script for Gamma spectrometric analysis of soil samples for sample identification	2021-06-17	-	2019	-	-
			Analysis of alpha, beta and gamma emitters by radiochemical spectroscopic techniques	2021-06-17	Ioannis Paschalidis, Leja Rovan, Borut Smodiš and Marko Štrok	2019	COPYRIGHT	The web fot this course can be inproved o chage the interface to more userfrienly mode. - there are photos with NO copyright in the Basic of analytical radiochemistry
			Determination of uranium in water	2021-06-17	ilona matveyeva, Sholpan Nazarkulova and Marko Štrok	2019	-	-
			Behaviour of radionuclides in the biosphere	2021-06-17	-		ERROR	The videos links use Flash Player and Since Adobe no longer supports Flash Player after December 31, 2020 and blocked Flash content

SOURCE	Cinch Moodle: Course categories	Course sub_categories	COURSE	Date checked	COPYRIGHT/Teacher	YEAR	ISSUE	COMMENTS & RECOMENDATIONS
	Learning and Training Courses		Behaviour of radionuclides in the biosphere	2021-06-17	-		ERROR	The videos links use Flash Player and Since Adobe no longer supports Flash Player after December 31, 2020 and blocked Flash content
		Dosimetry of ionizing radiation	Chemical dosimetry	2021-06-17	-	2019	-	-
			Interactive Screen Experiment "Dose Calibration in Gamma Field"	2021-06-17	-	-	-	-
			Fundamentals on Chemical Dosimetry	2021-06-22	Elena Macerata	-	-	-
		Nuclear Industry	Chemistry of cooling circuits of NPP	2021-06-22	-	-	-	-
		RoboLabs	PAuLa	2021-06-22	v.pottgiesser@irs.uni-hannover.de	-	-	content
			IonLab	2021-06-22	v.pottgiesser@irs.uni-hannover.de	-	-	-
			GammaLab	2021-06-22	v.pottgiesser@irs.uni-hannover.de	-	-	-
		Nuclear Forensics	Introduction to Nuclear Forensics	2021-06-22	-	-	-	-
	Summer Schools	ASGARD Nuclear Fuel Characteriazation Course (2014)	-	2021-06-22	-	2014	-	they sre restricted until a required score is archieve.
		ASGARD Stable Isotope Separation Course (2013)	-	2021-06-22	-	2013	-	they sre restricted until a required score is archieve.
		SACSESS, ASGARD and CINCH Working with Plutonium Course (Gothenburg 2015)	-	2021-06-22	-	2015	-	they sre restricted until a required score is archieve.
		TALISMAN Summer School on Actinides (Marcoule 2014)	-	2021-06-22	-	2014	-	-
	GEN IV Webinars	List of GEN IV Webinars	-	2021-06-22	-	-	-	-
	NAMP Radiochemistry Webinars	List of NAMP Webinairs	-	2021-06-22	-	-	-	-
		List of NAMP Webinairs	-	2021-06-23	-	-	-	-
	NucWik Content	Nuclear and Radiochemistry Textbook	-	2021-06-23	-	-	-	Link broken: nucwik.wikispaces.com unexpectedly closed the connection.
		Videolectures of Learning and Training Courses	-	2021-06-23	-	-	-	The videos links use Flash Player and Since Adobe no longer supports Flash Player after December 31, 2020 and blocked Flash content
		Videolectures of Summer Schools	-	2021-06-23	-	-	-	-
	High School Material	Background Information	-	2021-06-23	Lucy Platts	-	-	-
		Teacher Page	-	2021-06-23	Lucy Platts	-	-	-
		Student Page	-	2021-06-23	Lucy Platts	-	-	-
	Fundamental requirements	Basic Course on Ionizing Radiation	-	2021-06-23	v.pottgiesser@irs.uni-hannover.de	-	-	content
		Introduction to Nuclear Chemistry	-	2021-06-23	-	-	-	-
		Radiation Protection for Laboratory Exercises	-	2021-06-23	Nick Evans	-	-	CHAPTER 5: Radiation Safety and Health Hazards
		Introduction to Radiation Protection	-	2021-06-23	-	-	-	they sre restricted until a required score is archieve.
	Courses Playground	These section are in grey, no accesible for the public	-	2021-06-23	-	-	-	-
	Materials and Modules		-	2021-06-23	-	-	-	-