EUROPEAN COMMISSION
Community Research

SEVENTH FRAMEWORK PROGRAMME

CINCH

CINCH

(Contract Number: FP7-CA-249690)

DELIVERABLE D4.4

Joint dedicated training course "Hands-on Training in Nuclear Chemistry"

Lead Beneficiary: **CTU**

Due date of Deliverable: **31/10/2012** Finalised on: **24/01/2013**

Authors:	Václav Čuba, Jan John, Mojmír Němec

For the Lead Beneficiary	**Reviewed by Workpackage Leader**	**Approved by Coordinator**
Václav Čuba	**Jan John**	**Jan John**

Start date of project: **01/02/2010** Duration: **36 Months**
Project Coordinator: Jan John
Project Coordinator Organisation: CTU in Prague Revision: (0)

Project co-funded by the European Commission under the Euratom Research and Training Programme on Nuclear Energy within the Seventh Framework Programme		
Dissemination Level		
PU	Public	**X**
RE	Restricted to a group specified by the partners of the CINCH project	
CO	Confidential, only for partners of the CINCH project	

EXECUTIVE SUMMARY

Joint dedicated "Hands-on Training in Nuclear Chemistry" course was organized at CTU in Prague. The course was aimed at both senior non-nuclear chemists and master/PhD students in chemistry (non-nuclear or radiochemistry), providing the background necessary for later enrolment into the general purpose education/training modular courses covering the more specialized fields of their activities at the end-users.
The two-week course was run for 10 trainees. The teachers were recruited mainly from the CINCH Consortium, but also from the Czech Academy of Sciences or CEA Saclay. The trainees were recruited from the candidates proposed by the end-users (both industrial and academic).

All information regarding trainees, teachers and lectures, including all presentations, are available in the e-version of this course on CINCH Moodle at: http://193.51.253.155/cinch/

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

WP 1
☐ Task 1.1 ☐ Task 1.2 ☐ Task 1.3 ☐ Task 1.4 ☐ Task 1.5 ☐ Task 1.6

WP 2
☐ Task 2.1 ☐ Task 2.2 ☐ Task 2.3

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

WP 4
☐ Task 4.1 ☐ Task 4.2 ☐ Task 4.3 ☒ Task 4.4 ☐ Task 4.5 ☐ Task 4.6 ☐ Task 4.7

WP 5
☐ Task 5.1 ☐ Task 5.2 ☐ Task 5.3

WP 6
☐ Task 6.1 ☐ Task 6.2 ☐ Task 6.3 ☐ Task 6.4 ☐ Task 6.5 ☐ Task 6.6

OUTLINE

1 INTRODUCTION

Joint dedicated “Hands-on Training in Nuclear Chemistry” course was held at CTU in Prague Czech Republic, during 3-14th December 2012. It was focused on the fundamentals of nuclear chemistry and basic hands-on laboratory training in radiochemistry. The Course Brochure is attached as an Appendix.

Among 10 trainees, three were from University of Leeds (GB), three from Charles University Prague (CZ), two from Nuclear Research Institute Řež (CZ), one from The National Institute for Nuclear, Chemical and Biological Protection (CZ) and one from Temelín nuclear power plant (CZ).

There were six external teachers coming from Chalmers TU (SWE), University in Oslo (NOR), University in Helsinky (FIN), CEA INSTN Saclay (FR), Institute of nuclear physics of the ASCR (CZ) and Université de Lorraine (FR).

Eight internal teachers were drawn from the staff of Faculty of nuclear sciences and physical engineering CTU in Prague. Furthermore, four technical staff from CTU in Prague were involved in the course organization.

2 COURSE ORGANIZATION

The course was organized in two weeks. The basic outline was lectures in the morning, laboratory exercises in the afternoon. There were few exceptions due to current reconstruction of CTU building, most notably in Thursday of the first week, only lab exercises were running whole day and in Friday, only lectures were running whole day. Theoretical part of the course consisted of 40 contact teaching hours including calculation exercises, laboratory exercises constituted another 40 contact teaching hours.

The external teachers were invited to provide lectures on specific topics; they usually stayed only for one day, so that the costs were kept down. Two thematically fitting lectures, running coincidentally for different purposes (radiation chemistry and nuclear fusion) were incorporated into the course curriculum, too, to further increase the level of expertise of the trainers while not increasing the total costs.

Internal teachers were drawn from the staff of CTU in Prague, Faculty of nuclear sciences and physical engineering, Department of nuclear chemistry and Department of dosimetry and application of ionizing radiation.

2.1 Daily organization

Morning lectures: 8:30-12:30

Lunch break till: 14:00.

Afternoon exercises: 14:00-18:00

For detailed description of course organization, see Appendix 1.

3 THEORETICAL PART

For the detailed description of the content of each topic, see Appendix 2.

3.1 Fundamentals of nuclear chemistry 1

This topic was covered by 6 hours of lectures and 2 hours of calculation exercises. The teachers were Petr Beneš, Jon-Peter Omtvedt and Václav Čuba.

3.1.1 Content:

Structure and properties of atomic nuclei.
Classification of radionuclides.
Kinetics of radioactive decay. Radioactive equilibria.
Binuclear reactions. Yield of nuclear reactions.
Natural radioactivity. Radioactive decay chains.

3.2 Fundamentals of nuclear chemistry 2

This topic was covered by 8 hours of lectures and 2 hours of calculation exercises. The teachers were Jan John, Sophie Le Caër, Gérard Bonhomme and Václav Čuba.

3.2.1 Content:

Nuclear fission, fission products.
Hot atoms chemistry. Szilard-Chalmers system.
Nuclear fusion.
Radiation chemistry.
Actinides and transactinides.

3.3 Radiation detection and dosimetry, Radiation protection

This topic was covered by 7 hours of lectures and 1 hours of calculation exercises. The teachers were Jan John, Jiří Martinčík and Václav Čuba.

3.3.1 Content:

Interaction of IR with matter (alpha, gamma, beta, neutrons).
Detection of ionizing radiation (detector types, principles).
Dosimetry of ionizing radiation. Radiation protection.

3.4 Separation methods in radiochemistry

This topic was covered by 7 hours of lectures and 1 hours of calculation exercises. The teachers were Christian Ekberg and Mojmír Němec.

3.4.1 Content:

Separations in radioactive and trace systems.
Extraction methods (L-L, principles, instrumentation).
Chromatography (principles, instrumentation).
Other separation methods used in nuclear chemistry.

3.5 Radioanalytical chemistry

This topic was covered by 6 hours of lectures. The teachers were Jan Kučera and Jukka Lehto.

3.5.1 Content:

Activation analysis.
Determination of selected radionuclides.

4 LABORATORY EXERCISES

Laboratory exercises consisted of 40 contact teaching hours. They were ensured by four teachers – Mojmír Němec, Kateřina Čubová, Irena Špendlíková and Soběslav Neufuss. A Laboratory Manual was compiled for the purpose of this course and is available at CINCH Moodle at http://193.51.253.155/cinch/file.php/10/Lab/Hands-on_Manual_121204.pdf

The trainees were working in four groups of two or three people, each group having a different exercise at a given day. In Friday of the second week, each group prepared a presentation of two selected exercises.

The exercise in Reactor DNAA (delayed neutron activation analysis) of uranium and thorium samples was combined with an excursion on the training nuclear reactor Vrabec (The Sparrow) VR-1operated by CTU.

4.1.1 List of exercises

Handling of radioactive materials, preparation and dilution of radioactive solution.

Contamination survey, decontamination of surfaces, smear samples.

Extraction of uranium in the water-TOA system.

Preparation of the chromatographic column, ^{234}Th-^{234m}Pa radionuclide generator or ^{137}Cs-^{137m}Ba generator.

Liquid scintillation counting, gross alpha and beta measurement.

Szilard-Chalmers reaction – separation of nuclear isomers.

Determination of ^{137}Cs in natural waters, high resolution gamma ray spectrometry.

Plutonium determination, alpha spectrometry.

5 FEEDBACK

The feedback provided by the trainees was mainly positive. Nevertheless, following conclusions may be drawn based on their comments.

Overall feeling: the structure of the course was well set up. The presence of top specialists as teachers was significant highlight of the course. Its structure was well thought out and time slots for all parts of the course were reasonable.

Recommendations for potential improvements: Better structure of laboratory manuals would help, including some instructional videos on basic chemical techniques. Some lectures could be less "intensive" regarding the amount of information provided. There could be fewer calculation exercises, with longer time spent on each exercise.

The feedback received will be used to further improve the content and schedule of the course before the future runs.

6 CONCLUSIONS

1) CINCH modular "hands-on" training course was successfully implemented at CTU in Prague in the one before the last phase of the course development based on the IAEA Systematic Approach to Training (SAT) for nuclear plant personnel (the five phases in this approach are: Analysis, Design, Development, Implementation, and Evaluation).
2) It was two week course, consisting of 80 contact teaching hours.
3) The course was organized with the help of external teachers, giving lectures in their field of expertise.
4) The course had two main parts – theoretical part (40 teaching hours) and laboratory exercises (40 teaching hours).
5) Trainees' feedback was mainly positive, their input will be used to further improve the content and schedule of the course before the future runs.
6) All information regarding trainees, teachers and lectures, including all presentations, are available on CINCH Moodle at: http://193.51.253.155/cinch/

APPENDICES

Appendix 1

Schedule and content of the course *(1st week, 40 hours, max 12 students)*			
8:30 - 12:30		Lunch	14:00 – 18:00
Monday	3.12.2012		
Fundamentals of nuclear chemistry (FNC 1-1.1 and 1-1.2) Structure and properties of atomic nuclei. Classification of radionuclides. Kinetics of radioactive decay. Radioactive equilibria. Natural radioactivity. Radioactive decay chains. **Beneš**			**Practical exercises**
Tuesday	4.12.2012		
Radiation detection and dosimetry, radiation protection (DDP 1.1 and 1.2) Interaction of IR with matter. Radiation protection. Dosimetry of ionizing radiation. **Martinčík**			**Practical exercises**
Wednesday	5.12.2012		
Fundamentals of nuclear chemistry (FNC 1-2.1 and 1-2.C) Binuclear reactions. Yield of nuclear reactions. **Omtvedt** Calculation exercises. **Čuba**			**Practical exercises**
Thursday	6.12.2012		
Practical exercises			**Practical exercises**
Friday	7.12.2012		
Fundamentals of nuclear chemistry (FNC 2-2.1) Radiation chemistry. (DNC Seminar) **Le Caër**			**Fundamentals of nuclear chemistry (FNC 2-1.1 and 2-1.2)** Nuclear fission, fission products. Hot atoms chemistry. Szilard-Chalmers system. Actinides and transactinides. **John**
Radiation detection and dosimetry, radiation protection (DDP 2.1) Detection of ionizing radiation – Part 1. **John**			

Appendix 1

Schedule and content of the course *(2nd week, 40 hours, max 12 students)*			
8:30 - 12:30		Lunch	14:00 – 18:00
Monday	10.12.2012		
Fundamentals of nuclear chemistry (FNC 2-2.C) Calculation exercises. **Čuba**			**Practical exercises**
Radiation detection and dosimetry, radiation protection (DDP 2.2) Detection of ionizing radiation – Part 2. **John**			
Radiation detection and dosimetry, radiation protection (DDP 2.C) Calculation exercises **Čuba**			
Tuesday	11.12.2012		
Separation methods in radiochemistry (SEP 1.1 and 1.2) Separations in radioactive and trace systems. Extraction methods (principles, instrumentation). **Ekberg**			**Practical exercises**
Wednesday	12.12.2012		
Radioanalytical methods (RAM 1) Activation analysis. **Kučera**			**Practical exercises**
Practical exercises			**Fundamentals of nuclear chemistry (FNC 2-3)** Nuclear fusion. (FNSPE Colloquium) **Bonhomme**
Thursday	13.12.2012		
Separation methods in radiochemistry (SEP 2.1, 2.2 and 2.C) Chromatography (principles, instrumentation). Other separation methods used in nuclear chemistry. **Němec**			**Practical exercises**
Friday	14.12.2012		
Radioanalytical methods (RAM 2.1 and 2.2) Determination of selected radionuclides. **Lehto**			**Presentations of participants and results evaluation**

Appendix 1

	3.12.2012	4.12.2012	5.12.2012	6.12.2012 am	6.12.2012 pm	10.12.2012	11.12.2012	12.12.2012	13.12.2012	14.12.2012
Group 1	**PIP**	**CON**	**EXTR**	**GAMMA**	**GEN**	**LSC**	**ALPHA**	**BROM**	**ZNAA**	
Group 2	**PIP**	**CON**	**BROM**	**GAMMA**	**LSC**	**ALPHA**	**EXTR**	**GEN**	**ZNAA**	
Group 3	**CON**	**PIP**	**GEN**	**LSC**	**ALPHA**	**GAMMA**	**BROM**	**EXTR**	**ZNAA**	
Group 4	**CON**	**PIP**	**LSC**	**EXTR**	**BROM**	**GAMMA**	**GEN**	**ALPHA**	**ZNAA**	

PIP	Handling of radioactive materials, preparation and dilution of radioactive solutions
CON	Contamination survey, decontamination of surfaces, smear samples
LSC	Liquid scintillation counting, gross alpha and beta measurement
BROM	Szilard-Chalmers reaction – separation of nuclear isomers
GEN	Preparation of the chromatographic column, ^{234}Th-^{234}mPa radionuclide generator or ^{137}Cs-^{137m}Ba generator
GAMMA	Determination of ^{137}Cs in natural waters, γ–ray spectrometry
EXTR	Extraction of uranium in the water – TOA system
ALPHA	Plutonium determination, alphaspectrometry
ZNAA	Reactor DNAA (delayed neutron activation analysis) of uranium and thorium samples at reactor Vrabec VR-1

Theoretical part of the course

(40 contact teaching hours[1] of lectures + calculation exercises)

Topic 1: **Fundamentals of nuclear chemistry 1** *(6 + 2 hrs)*

- Structure and properties of atomic nuclei.
- Classification of radionuclides.
- Kinetics of radioactive decay. Radioactive equilibria.
- Binuclear reactions. Yield of nuclear reactions.
- Natural radioactivity. Radioactive decay chains.

Topic 2: **Fundamentals of nuclear chemistry 2** *(8 + 2 hrs)*

- Nuclear fission, fission products.
- Hot atoms chemistry. Szilard-Chalmers system.
- Nuclear fusion.
- Radiation chemistry.
- Actinides and transactinides.

Topic 3: **Radiation detection and dosimetry, radiation protection** *(7 + 1 hrs)*

- Interaction of IR with matter (alpha, gamma, beta, neutrons).
- Detection of ionizing radiation (detector types, principles).
- Dosimetry of ionizing radiation. Radiation protection.

Topic 4: **Separation methods in radiochemistry** *(7 + 1 hrs)*

- Separations in radioactive and trace systems.
- Extraction methods (L-L, principles, instrumentation).
- Chromatography (principles, instrumentation).
- Other separation methods used in nuclear chemistry.

Topic 5: **Radioanalytical chemistry** *(6 + 0 hrs)*

- Indicator methods. Isotope dilution analysis. Radio-reagent methods.
- Interaction methods.
- Determination of selected radionuclides.

[1] 1 teaching hour (th) = 50 minutes. Usually in blocks of 2 teaching hours (1 hour 40 minutes), followed by 20 minutes break

Topic 1: Fundamentals of nuclear chemistry 1

(6 + 2 ths, Blocks FNC 1-1 and FNC 1-2)

1.1 Structure and properties of atom and atomic nuclei

- Nucleons and their role in the nuclear makeup
- Other particles connected to radioactivity – electrons, positrons, (anti)neutrinos, alpha, gamma...
- Bohr atomic model, liquid drop model and shell models
- Nuclear forces, stability and binding energy of the nucleus
- Definition of the terms: element, isotope, nuclide, Z, N, A

1.2 Classification of radionuclides

- Stability dependence on N and Z numbers
- Radioactivity, types of radioactive decay and its occurrence, emitted particles
- Table of nuclides
- Natural and artificial radionuclides

1.3 Kinetics of radioactive decay, radioactive equilibria

- Decay law, activity vs. mass of the radinuclide
- Single and chain decay dependences, decay equilibria
- Definitions: Bq, eV, lambda, $T_{1/2}$
- Radionuclide generators

1.4 Binuclear reactions, yield of nuclear reactions

- Basic classification of the nuclear reactions
- Types of binuclear reactions and their mechanism
- Yield and crossection
- Important nuclear reactions (fission, activation, p-n, alfa-n)

1.5 Natural radioactivity, radioactive decay chains

- Sources of natural radioactivity and radionuclides
- Terestrial and cosmic radiation
- Primordial radionuclides, natural decay chains
- Cosmogenic radionuclides

Schedule

Block	Duration	Contents	Teacher[2]
FNC 1-1.1	2 ths	Topics 1.1 + 1.2	Beneš
FNC 1-1.2	2 ths	Topics 1.3 + 1.5	Beneš
FNC 1-2.1	2 th	Topic 1.4	Omtvedt
FNC 1-2.C	2 ths	Calculation exercises	Čuba

[2] *Teachers colour codes:*
No colour – CTU teachers
CINCH consortium teachers
External teachers

Topic 2: Fundamentals of nuclear chemistry 2

(8 + 2 ths, Blocks FNC 2-1, FNC 2-2 and FNC 2-3)

2.1 Nuclear fission and fission products

- Kinetic and energetic conditions for fission
- Camel curve and yield of the fission products, short decay chains
- Chain neutron reaction, principles of nuclear fission reactors, radioactive waste problem

2.2 Reactions of hot atoms. Szilard-Chalmers system

- Hot atoms formation, nuclear recoil
- Szilard-Chalmers systems and mechanism

2.3 Thermonuclear fusion

- Fusion reactions - general principles and past achievements
- Fusion reactors - ITER: status and challenges
- Stellarators and ESTELL project
- Perspectives for fusion energy

2.4 Radiation chemistry

- Mechanism of ionization, radiolysis of matter
- Formation and relaxation of excited atoms and molecules
- Track effects, reactions of reactive intermediates
- Effects of dose rate, radiation chemical yields.
- Radiation effects on speciation, physical properties.

2.5 Actinides and transactinides

- Overview, preparation and production
- Physical and chemical properties
- Utilization of actinides in industry etc.

Schedule

Block	Duration	Contents	Teacher
FNC 2-1.1	2 ths	Topics 2.1 + 2.2	John
FNC 2-1.2	2 ths	Topic 2.4	Le Caër
FNC 2-2.1	2 ths	Topic 2.5	John
FNC 2-2.C	2 ths	Calculation exercises	Čuba
FNC 2-3	2 ths	Topic 2.3	Bonhomme

Topic 3: Radiation detection and dosimetry, radiation protection

(*7 + 1 ths, Blocks DDP 1 and DDP 2)*

3.1 Interaction of IR with matter (alpha, gamma, beta, neutrons)

- Interaction of charged particles (including electrons), Bragg curve
- Interaction of gamma and X radiation, exponential law, attenuation coefficients
- Interaction of neutrons

3.2 Detection of ionizing radiation (detector types, principles)

- Principles of IR detection and fundamental mechanism, main detector types
- Gas detectors (principle, types and construction, utilization)
- Scintillation detectors (principle, types and construction, utilization)
- Semiconductor detectors (principle, types and construction, utilization)
- Other detectors

3.3 Dosimetry and radiation protection

- Quantities in dosimetry and the units used
- Measurement and visualization of radiation dose, active and passive dosimeters
- Open and closed ionizing radiation sources
- Shielding
- Screening, quantification and limits of contamination
- Principles of radiation protection, ALARA
- Legislation

Schedule

Block	Duration	Contents	Teacher
DDP 1.1	2 ths	Topics 3.1 + 3.3 (items 5-7)	Martinčík
DDP 1.2	2 ths	Topic 3.3 (items 1-4)	Martinčík
DPP 2.1	2 ths	Topic 3.2 (items 1-3)	John
DPP 2.2	1 th	Topic 3.2 (items 4 and 5)	John
DPP 2.C	1 th	Calculation exercises	Čuba

Appendix 2

Topic 4: Separation methods in radiochemistry

(*7 + 1 ths, Blocks SEP 1 and SEP 2)*

4.1 Separations in radioactive and trace systems

- trace amount of the radionuclides and its influence on chemical behaviour, sorption
- half-life and daughter nuclide creation
- radiation and radiolytic influence on the separation systems
- radiation protection in radiochemical separations, equipment and shielding

4.2 Extraction methods (L-L, principles, instrumentation)

- extraction techniques, examples of two phase systems,
- distribution ratio and constant, E%, separation factor, repeated extraction
- extraction of chelates and its description
- extraction of ion associates, agents
- other liquid-liquid extraction systems
- instrumentation (glass, devices, batch x flow...)

4.3 Chromatography (principles, instrumentation)

- chromatography principles, plate count and height, definition of phases
- separation factor on the column, flow rate, bed, dead and elution volumes
- extraction chromatography
- ion exchangers and IE chromatography
- detection of the analytes, chromatograph construction
- column preparation, commercially available materials

4.4 Other separation methods used in nuclear chemistry

- modern separation methods and their application in nuclear chemistry
- principles of separation via mass difference
- enrichment and separation of isotopes, utilization of isotopically modified materials
- radiochemistry/nuclear techniques for pure isotope preparation

Schedule

Block	Duration	Contents	Teacher
SEP 1.1	2 ths	Topics 4.1 + 4.2 (items 1 and 2)	Ekberg
SEP 1.2	2 ths	Topic 4.2 (items 3-5)	Ekberg
SEP 2.1	2 ths	Topic 4.3	Němec
SEP 2.2	1 th	Topic 4.4	Němec
SEP 2.C	1 th	Calculation exercises	Němec

Appendix 2

Topic 5: Radioanalytical methods

(*6 ths, Blocks RAM 1 and RAM 2)*

5.1 Activation analysis

- Principles, sensitivity, requirements
- Instrumental setup, comparison to non-nuclear methods

5.2 Non-activation interaction methods

- Absorption methods
- Emission methods

5.3 Determination of selected radionuclides

- Sample collection and its philosophy
- Natural cosmogenic radionuclides – isotopes of H, Be, C, Al, Cl...
- Natural primordial radionuclides – isotopes of K, ...Po, Ra, Rn, U, Th
- Artificial radionuclides (fission and activation) – Cs, Sr, Co, I, Tc
- Transuranium elements Am, Pu, Cm

Schedule

Block	Duration	Contents	Teacher
RAM 1.1	2 ths	Topics 5.1, 5.2, 5.3 and 5.5	John
RAM 1.2	2 ths	Topic 5.4	Kučera
RAM 2.1	2 ths	Topic 5.6 – Part 1	Lehto
RAM 2.2	2 ths	Topic 5.6 – Part 2	Lehto